



# PROCESS PRACTICES

*in the*

# AIRCRAFT INDUSTRY

BY

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*To*

K. S. K.

WITHOUT WHOSE PATIENCE AND  
HELP THIS BOOK WOULD NEVER  
HAVE BEEN WRITTEN





## PREFACE

In this book the author has attempted to fill the need for a reference and instruction book, with supplementary descriptive literature, concerning the processes, methods, and materials employed in the aircraft industry. Owing to continual development and changes in design, there have been corresponding changes in processes, methods, and materials in the last ten years. These new methods of production, sponsored by this change, have brought about modification of requirements, as well as additional requirements.

The suggested conditions for materials and process methods shown here are the result of the author's coordination and cooperation with military and naval procurement agencies.

The author has endeavored to arrange the separate sections and chapters of the book according to the chronological order of production flow, so that the reader may follow the airplane or part from the point at which raw stock is received to final acceptance of the part for installation or flight test.

It is with great pleasure that the author acknowledges his indebtedness to his secretary, Luella Rollins, for her help in compiling the material, and to John Sobesky, for his invaluable help in the construction of drawings.

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It must be realized that in order to secure the necessary reference, which is more or less standard in the aircraft industry, though variously compiled, use of such data must be made by reference and abstraction. Full acknowledgment and indebtedness are given to the various material, part, and plane manufacturers directly and indirectly referred to throughout the book; without their help and the information contained

in their numerous publications, the reference tables and remarks included would not have been possible.

The serious and extensive war effort in which we are now engaged brings home the tactical and death-dealing efficiency of superiority in air power. The dire necessity of creating ground crews, mechanics, and other skilled aircraft labor becomes more apparent as each day passes. The race for a determined victory which inevitably must be ours is, and will be, governed by our ability to "Keep 'em Flying," and it is earnestly hoped that, by the publication of this book, information and instruction will be made available for the progress of aviation.

FRANK D. KLEIN, JR.

DETROIT, MICH.

## ACKNOWLEDGMENTS

As referred to in the Preface, numerous acknowledgments must be made for material used in the following chapters of this book.

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## PART I

### CHARACTERISTIC AIRCRAFT RAW MATERIALS

In the majority of cases, raw materials used in the construction of aircraft are the result of much research and development to secure five important elements:

1. Strength.
2. Lightness.
3. Ease of processing.
4. Safety.
5. Dependability.

In order to meet these requirements, the products are necessarily highly specialized groups of materials meeting extraordinary tests. A group of manufacturers who have specialized in the aviation field are the pioneers in the manufacture of products. Procurement of products has been simplified, yet controlled, by applicable governing specifications that restrict the source of supply to dependable, approved manufacturers, thoroughly cognizant of the requirements and the reasons for restriction. These manufacturers have shared in design, research, development, manufacture, and final test. By sharing in the development, they know by trial the necessity of conforming to the tolerance requirements. Therefore, many attempts of inexperienced manufacturers to compete result for a time in misfortune and delay. The application of untried, unapproved materials as a substitute for proper materials can result only in failures and rejections.

It is highly important that operators, designers, and manufacturers be thoroughly informed about and conversant with the aviation-material market. Automobile manufacturers who realize the trend in transportation, as well as the significance of the airplane in military defense, upon entering the aviation manufacturing field, have criticized engineers and other experienced "aircraft"-trained technicians for their restricted sense of detail and conformity to quality standards. However, let it be repeated here and be forever borne in mind that a sense of detail, including even the most insignificant part in the make-up of an airplane, has saved many a pilot's life. Too much, therefore, cannot be said concerning the control of the quality and uniformity of aircraft raw materials and the understanding of their market and manufacture and the methods of their procurement.

In the following chapter, an attempt is made to simplify the understanding of procurement detail. A small but descriptive effort is made to hinge upon the requirements necessary.





## CHAPTER I

### PROCUREMENT METHODS AND REFERENCE

The procurement of aircraft raw materials for military work entails the knowledge of standard procurement routines established by the Federal contracting agencies. In general, the purchasing of military material does not differ from commercial procurement except that the raw materials must meet the requirements of the governing military specification.

We are dealing only with military materials in this discussion; therefore, the references made are to Army, Navy, or Federal specifications. For the purpose of coordinating effort, it is suggested that a system be established whereby the latest available data on current specifications may be kept and be available to all concerned. Such a system has been devised in the following pages in a Condensed Index of Specifications. Although this form is given as an illustration, it should not be considered inflexible. The specification numbers are current with the date of writing of this book and are given only as examples. If a system of this kind is used, monthly revisions should be made in order that the latest specifications may be given and used. A number of examples have been given in the following. Follow them to acquaint yourself with the general routine.

1. *Example:* You are concerned with ordering 5,000 lb. 24ST Alclad aluminum-alloy sheet.

Step 1: Turn to the page in the Condensed Index of Specifications, the heading of which is Metals—Aluminum and Aluminum Alloys.

Step 2: Follow the columns on down to the proper page, where you will find Alclad, under which 24ST (HT) is listed. (HT = heat-treated.)

Step 3: Follow the listing across, showing the following information:

1. S.A.E. specifications 24ST.
2. Current Army specifications 11067 Type 11.
3. Current Navy specifications 47-A8 Condition T.
4. AN tensile strength 56,000 lb.

a. Your purchase order and requisition should therefore bear this information.

2. *Example:* Purchased standard parts (AN). Standard parts incorporated by the designer in his design are based on either or both of the following:

- a. AN standards.
- b. N.A.F. standard.

These parts are universal throughout the aviation industry and constitute parts that, for the purpose of standardization, apply to all airplane designs.

1. *Example:* The designer has called out on his drawing the use of AN430DD2-3 rivets.

Step 1: Turn to the index in the "AN Standards Book" (obtainable from U.S. Army Air Forces), and find AN430 under Rivets.

Step 2: Find page 430. Now, AN430 denotes only the standard number of the aluminum rivet. DD denotes the type of material that is 24ST aluminum alloy; 2 denotes the fact that the diameter of the rivet is  $\frac{3}{32}$  in.; 3 denotes the fact that the rivet is  $\frac{3}{16}$  in. long.

Step 3: Next, at the bottom of the page, consult Engineering Information, and find DD. This then tells you that the minimum shear strength should be 35,000 p.s.i.; also, that the rivet must be heat-treated before being used.

1. Your purchase order and requisition would read as follows:

- a. Amount desired.
- b. AN430DD2-3 rivets.
- c. Minimum shear strength 35,000 p.s.i.
- d. No heat treatment required.

2. Your purchase order lacks one requirement—the surface treatment—*i.e.*, whether the rivet is to be supplied anodically treated or untreated. This will depend on whether you choose to apply the anodizing treatment yourself or to purchase the rivets anodized. This information is usually covered by the policy established by the plant management. As a general rule, pure aluminum, 2S-3S, 4S, and 52S aluminum alloys require no anodic treatment; all others must be anodized. Therefore, regardless of where the work is done, if the rivet does not fall in the preceding class, it should be anodized.

2. *Example:* The designer has called out on his drawing the use of NAF1023-15 Type D-25 exterior Light.

Step 1: Turn to the index in the "N.A.F. Standards Book" (procurable through the U.S. Navy Bureau of Aeronautics), and find Light. Follow across to drawing 1015.

Step 2: Turn to drawing 1015. Find the light conforming with the dash number. This gives the dimensions required to allow placement in part or parts.

Step 3: Consult further the footnotes on purchasing.

1. Your purchase order and requisition should read:

- a. Amount.
- b. NAF1023-15 Type D-25 light exterior. Single contact.
- c. To be manufactured according to N.A.F. drawing 38690 ALT. 19. Each designer in many cases has developed a "Book of Standard Parts" of his own, which might contain an especially designed part or a variation of the part ordinarily found in the AN or N.A.F. book.

In general, purchasing of aircraft materials should always be done when possible from a standard group of supplies pre-established by test or some other suitable means. It is usually good practice to establish three

sources of supply for each item. This sometimes eliminates delay and often does away with "monopoly" price increases.

Army and Navy specifications appearing opposite each other do not indicate that they are identical in chemical and/or physical qualities. This arrangement merely indicates that they are nearly enough equivalent to be used for the same general purpose. Physical qualities must always be checked on the particular material being used in designing new parts or in substituting materials on old parts.

When no Army, Navy, or Federal specification is given for a material, the vendor's specification number or trade name should be specified with the term "or equivalent" added; or the material should be called out as commercially available.

Federal and Army-Navy specifications are listed under either or both the Army and Navy columns as approved for use. In a number of cases the most common use of a given material is included under remarks, for information. These materials are not necessarily limited to only the use indicated.

## CONDENSED INDEX OF SPECIFICATIONS

Title	S.A.E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Bearings: metal seal antifriction AN200.....	—	25524	—	42B8	—	—	For equipment controls. Not stain- less
Braids: bonding (large) tinned copper.	—	40229	—	N.A.F. drawing 29535-5	—	—	For air controls. Not stainless
Cable: control and structural:	—	None	—	22C5	—	—	For air and equipment control. Flexible 7 × 7 $\frac{1}{16}$ and $\frac{3}{32}$ diam- eter.
Cable, bronze, extra flexible 7 × 19.....	—	48-35	48-22	22C6	C-60	—	Extra flexible 7 × 19 $\frac{1}{8}$ diameter and above
Cable, steel, flexible 7 × 7, tinned carbon.	—	48-35	—	Class A	Class A	—	
Cable, steel, extra flexible 7 × 19 tinned carbon.	—	48-35	—	22C6	C-69	—	
Cable, steel, flexible and extra flexible corrosion resistant.	—	48-36	10298	Class B	Class B	—	
				49C11	22C4	—	
				Class A	—	—	
				Class B	—	—	
Cable: electrical:	—	95-28003	—	AN9512	M216b	—	
High-tension ignition.....	—	95-27074	—	M393	15C5	—	
Power and lighting.....	—	95-27273	—	None	—	—	
(shielded).....	—	—	—	N.A.F. drawing 29720-2	—	—	
Wire, antenna—rel.....	—	—	—	N.A.F. drawing 29720-6	—	—	Radio equipment only
Wire antenna—fixed.....	—	—	—	—	—	—	
Castings:	—	93-24519	—	49C10	—	—	
Control cable, flexible.....	—	26545	—	—	—	—	
Smooth contour, loading grade.....	—	26547	—	—	—	—	
Smooth contour T. wheel.....	—	—	—	—	—	—	
Conduit:	—	AN-W-C561-32007	—	33T3	—	—	
Electrical, flexible.....	—	—	—	—	—	—	
Air-flexible aluminum.....	—	—	—	—	—	—	
Coolers:	—	None	—	C-73	49R2	—	
Oil.....	—	—	—	—	—	—	



CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S. A. E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Castings, Alcoa.....	195-T4 Navy 220-T4	—	—	46A1 Class 4 M186-B	—	N29,000	For structural parts. <i>Cannot be welded</i>
Castings, Alcoa.....	—	11309	—	—	—	AN42,000	Highest strength aluminum alloy casting for aircraft use. <i>Cannot be welded</i> . Use only on highly stressed parts
Castings, aluminum die.....	—	57-93-1	—	None	—	Grade 1 32,000 Grade 2 33,000	Grade 1—Alcoa 13 Grade 2—Alcoa 85
Foil aluminum.....	—	11074	—	47A5	—	AN65,000	Heat-treated 14ST for general purposes
Forgings, aluminum.....	14S	QQ-A-367 Grade 5	57-153 Grades 1 and 3	Superseded by 46A7	—	—	—
Flat sheet, 2S aluminum.....	2S	57-151-1 Temper A	—	47A20 Temper	—	A15,500 (max.)	Annealed. For deep drawing spinning, etc. Weldable
Flat sheet, 2S aluminum.....	2S	57-151-1 Temper $1\frac{1}{2}$ H	—	$\frac{1}{2}$ H 47A4 Temper	—	A16,000	Weldable. $\frac{1}{2}$ hard for general use
Sheet 3S aluminum alloy.....	3S	QQ-A-359 $\frac{1}{2}$ H temper	—	$\frac{1}{2}$ H 47A4 Temper	—	AN19,500	$\frac{1}{2}$ hard. Weldable
Sheet, aluminum alloy.....	17S 17SC	QQ-A-353 Condition A	—	47A4 Condition A	—	AN35,000	Do not weld Temper desired must be specified on drawing
Sheet, aluminum alloy, aluminum covered, Alclad.....	17ST	Condition T	—	Condition T	—	AN55,000	—
Alclad.....	17S	Annealed	—	Condition A	—	AN30,000	Do not weld. Temper desired must be specified on drawing
Alclad.....	17ST	Quenched	—	Condition T	—	AN50,000	Do not weld. Temper desired must be specified on drawings
Sheet, 24S aluminum alloy.....	24S	57-152-6	11066	47A10	M-145 Annealed	AN35,000 (max.)	Do not weld. Temper desired must be specified on drawings
24So (annealed).....	24SO	Type 1	Annealed	Condition A	HT	—	Do not weld. Temper desired must be specified on drawings
24ST (HT).....	24ST	Type 2	HT	Condition T	—	AN62,000	Do not weld. Temper desired must be specified on drawings

24SRT(HT and R.)	Type 3	HT and R.	Condition <i>TR</i>	HT and R.	Do not weld. Temper desired must be specified on drawings
24SRT					
24S Covered	11067	—	47A8 Condition A	—	Do not weld. Temper desired must be specified on drawings
24SO	Type 1	—	Condition <i>T</i>	—	Do not weld. Temper desired must be specified on drawings
24ST (HT)	Type 2	—	Condition <i>TR</i>	—	Do not weld. Temper desired must be specified on drawings
24SRT (HT and R.)	Type 3	—	47A11 Temper A	—	Annealed—can be welded but with difficulty Consult materials department
Sheet, 52S aluminum alloy	QQ-A-318 Temper A	—	Temper $\frac{1}{4}$ H Temper $\frac{1}{2}$ H 44T19 Temper $\frac{1}{2}$ H	—	$\frac{1}{4}$ hard $\frac{1}{2}$ hard Purchased in $\frac{1}{2}$ hard condition. Only for electrical conduit and tubes attached by welding, such as filler necks
Sheet, 52S aluminum alloy	Temper $\frac{1}{4}$ H Temper $\frac{1}{2}$ H WW-T-483 Temper $\frac{1}{2}$ H	—	44T28 Condition <i>T</i>	—	Round, purchased in heat-treated temper unless otherwise specified.
Sheet, 52S aluminum alloy	10235 Condition B	—	44T31 Condition <i>T</i>	M280 Condition <i>T</i>	Do not weld. Streamlined, purchased in heat-treated condition unless otherwise specified. Do not weld
Tubing 24ST aluminum alloy	57-187-2 Grade 24	—	44T32 Condition A	—	Purchased in annealed temper only for fuel, oil, fire extinguisher instrument, and vent lines. Sizes in accordance with AN requirements
Tubing 24ST aluminum alloy	57-187-3 Temper A	11073			Do not torch-weld, without materials-department approval
Tubing 52SO aluminum alloy					Bound, purchased in heat-treated condition unless otherwise specified. Do not weld
Tubing	11326	—	44T21 Condition <i>T</i>	—	Streamline. Purchased in heat-treated condition only for Army. Do not weld
Tubing 17ST aluminum alloy	WW-T-786 Condition <i>T</i>	—	44T22 Condition <i>T</i>	—	
Tubing 17ST aluminum alloy	57-187-2 Grade 17	—			



CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S.A.E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Fastals (cont'd.): Brass, bronze, copper:							
Bars, rods, shapes, plates, sheets, and strips (brass).	—	QQ-B-611	57-161	47B2	—	See specifications	Commercial, grade, and temper desired must be specified on drawing
Bars, rods, shapes, plates, sheets, and strips (brass).	—	QQ-B-636	57-162	46B6	—	See specifications	Naval. Grade and temper desired must be specified on drawing
Bars, rods, shapes, plates, sheets, and strips (brass).	—	QQ-B-721	57-166A	46B15	—	See specifications	Type and temper desired must be specified on drawing
Bars, rods, shapes, plates, sheets, and strips, phosphor bronze.	—	QQ-B-746	57-167	46B14	—	See specifications	Grade and temper desired must be specified on drawing
Bars, rods, shapes, plates, sheets, and strips (copper).	—	QQ-C-501	57-154	47C2	—	See specifications	Army temper or Navy class must be specified on drawing
Bars, bronze.....	—	Hx-Ten-sl Grade 2 or equivalent	—	Hx-Ten-sl Grade 2 or equivalent	—	100,000 min.	A special high-strength bronze for use in bearings, journals, packing nuts, etc.
Castings, bronze.....	—	Hx-Ten-sl Grade 2 or equivalent	—	Hx-Ten-sl Grade 2 or equivalent	—	100,000 min.	
Castings, red brass.....	—	QQ-B-621 Composition A	57-76	46B11	—	AN30,000	Low strength, general use, not to be used to carry fluid or hold pressure
Castings, bronze, cored and solid.....	—	11306	—	None	—	See specifications	High strength and good corrosion resistance
Castings, bronze, manganese.....	—	QQ-B-726	57-81	49B3	—	AN65,000	
Castings, bronze, phosphor.....	—	QQ-B-691	57-70	46B5	—	AN35,000	Medium strength, free machining quality
Castings, bronze, aluminum.....	—	Composition 6 QQ-B-671 Grade A	57-78	Grade 1 46B18	—	AN65,000	High strength and very high corrosion resistance
Sheet and strip, brass.....	—	57-160	—	None	—	38,000	For use on radiator plates and shells only

Tubing, brass seamless.....	—	WW-T-791 Grade 2	—	44T15 Grade 2	—	None required	Purchased in annealed condition
Tubing, copper.....	—	WW-T-799 Type 2	57-188-1	WW-T-799 Type N	M70	None required	To be used only when specified by contractor
Tubing, Cu-Si bronze (Ever- due), seamless.....	—	57-192-1	11063	44T23	—	50,000	For cyanided parts. Tensile strength as received AN55,000 p.s.i.
Bars, carbon steel.....	—	AN-QQ-S-646-1020	57-107-9	AN-QQ-S-646-1020	46S22	As HT	Tensile strength in as received condition 55,000 p.s.i.
Bars, carbon steel.....	1025	AN-QQ-S-646-1025	—	AN-QQ-S-646-1025	—	No HT	For bolts and threaded parts. Purchased in annealed condition. Do not weld. Tensile strength as received AN65,000 p.s.i.
Bars, medium carbon nickel.....	2330	57-107-17	10074	46S21	—	As HT	Use for parts requiring hard wearing surface and tough, strong core, such as gears, pawls, etc. Drawing must indicate area and depth of case desired. Always purchased in annealed condition. Do not weld. Tensile strength as received AN50,000 p.s.i.
Bars, carburizing.....	2512	57-107-18	10066	EMS-3	—	As HT	Always purchased in annealed condition. Tensile strength as received 65,000
Bars, medium carbon.....	X-4130	57-107-19	10064	46S23 Grade A only	—	As HT	For unwelded fittings having a wide variation in thickness or having a thickness greater than 1 in. Con- suit materials department before using
Bars, medium carbon, chrome molybdenum.....	4140	10083	—	—	—	None	For heavy sections, high-strength fittings, and forgings. Purchased in annealed condition. Do not weld. Tensile strength as received AN70,000 p.s.i. depth hardens better
Bars, chrome, nickel molyb- denum—approximately S.A.E. X 4340.....	X4340	11062	—	46S28	—	As HT	

CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S.A.E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Bars, high carbon chrome, vanadium.	6150	AN-QQ-S-687	57-107-5	AN-QQ-S-687	46S24	As HT	May be used for some gears; always purchased in annealed condition. Do not weld. Tensile strength as received 65,000 p.s.i.
Bars, chrome, vanadium, high-carbon steel.	6150	AN-QQ-S-687	57-107-5	AN-QQ-S-687	—	As HT	Heavy-duty springs for oleos, etc. Manufacturing specification, A40092, N4987. Tensile strength as received AN65,000 p.s.i.
Bars, medium carbon, high chrome.	5123	57-107-13	10061	46S18 Grade 5	—	As HT	For high-strength machined parts. Stainless heat-treating magnetic. Always purchased annealed. Do not weld.
Bars, corrosion resistant.....	—	10079 Free machine condition 1A	—	46S18 Grade 7 Type D 46S26	—	As HT AN80,000	Annealed 18-8 Carpenter No. 8. Free machining or equivalent.
Bars, corrosion resistant.....	—	—	—	Grade 7 for forgings	—	AN80,000	Non-magnetic. For forgings. For machined parts and for reworking only
Bars and rods, Nickel-chrome-iron (Inconel), annealed.	—	INC. 57-174 Type 1 Class B	—	10082	—	—	Non-magnetic. For exhaust-system parts
Tool steel, Carbon and alloy	—	57-108	—	46S9	—	—	For tool kits, drill rod, hinge and dovetail pins. See specifications for grades and types
Castings, manganese steel.....	—	57-65	—	10812	None	None required	For parts requiring extreme hardness and ductility, as tail-skid shoes
Castings, steel.....	—	QQ-S-681	—	45-S-1	—	See specifications	See specifications for classes and uses
Castings, steel.....	—	57-64-1	11305	None	—	180,000 (max.)	For special use only. Consult materials before using

Footing, carbon, and alloy steel.	57-105	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT (See specifications) None required	This is a manufacturing specification. Steel. Number must also be specified on drawing. Extra soft. Low carbon. Use on commercial only or for deep forming for non-structural parts. For aircraft fittings and miscellaneous cyanided parts. Annealed. Do not weld. Not to be used without heat treating. Always purchased in annealed condition. Tensile strength as received AN65,000 p.s.i. Non-magnetic. For exhaust system or other torch-welded parts. Can be spot-welded. Is slightly magnetic 150,000 tensile strength for spot-welded parts. Do not torch-weld. Non-magnetic. For exhaust-system parts. Purchased in annealed condition only. Weldable.
Sheet or strip; carbon steel.....	1010	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; carbon steel.....	1010	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; carbon steel.....	1025	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet, strip; spring steel.....	1005	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; chrome molybdenum.	X-4130	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; Cr-Ni 18-8 stainless annealed.	18-8	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; Cr-Ni 18-8 stainless $\frac{1}{2}$ hard.	18-8 - $\frac{1}{2}$	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Sheet or strip; Ni-Cr-Fe (Inconel).	INC.	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Tubing, chrome molybdenum.	X-4130	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Tubing, mild carbon, seamless	1025	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Tubing, chrome molybdenum, streamlined.	X-4130 STR.	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded
Tubing, Cr-Ni, unstabilized, seamless 18-8 corrosion-resistant (annealed).	18-8	57-136-4	57-136-3	57-136-6	57-136-8	57-180-1	57-183	57-180-3	As HT	For hydraulic lines. Not to be welded

## CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S.A.E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Tubing, Cr-Ni-Cb, stabilized, welded 18-8 stainless annealed.	18-8	57-180-4 Grade 1SS (annealed)	10234	44T26 Grade 1SCb	—	AN80,000 (annealed)	Weldable. For exhaust system and parts. <i>Not to be used in hydraulic systems</i>
Tubing, Ni-Cr-Fe seamless, annealed Inconel.	INC.	57-174 Type 5 Class B	10082	49T13	T-44	AN80,000	Non-magnetic. For exhaust-system parts. Weldable
Tubing, Ni-Cr-Fr welded, annealed Inconel.	INC.	57-174 Type 6 Class A	10082	49T14	T-60	AN80,000	Non-magnetic. For exhaust-system parts. Not to be used in hydraulic systems. Weldable
Tubing, Cr-Ni-Cb, seamless, 18-8 stainless, annealed.	18-8	57-180-3 Grade 1SS	10233	44T25 Grade 1SCb	M55 Type 1	AN80,000	For exhaust system or other torch-welded parts. Not to be used in hydraulic system. Weldable
Magnesium-base alloys: Bars (B) and shapes (S) (extruded).	AM C578 or J-1	11320 Grade 1	—	M314 Alloy 8	—	(B) 40,000 (S) 38,000	Parts requiring moderate strength cannot be welded
Bars (B) and shapes (S), extruded, AM38 or H.	AM38 or M	11320 Grade 11	—	M314 Alloy 11	—	(B) 32,000 (S) 30,000	Lightly stressed parts. May be welded
Castings, sand AM265T6 or H	AM265 T6 or H	57-74-1 Condition HTA	—	M112 Alloy 4	—	32,000	Heat-treated and aged; all stressed parts. Cannot be welded
Castings, sand AM403 or M...	AM403 or M	None	—	Condition HTA M112	—	12,000	Lightly stressed parts requiring good weldability and maximum resistance to corrosion
Castings, die .....	—	11319	—	Condition AC M369	—	30,000	Lightly stressed parts. Do not weld
Forgings, AM(C575 or J-1) .....	AM-C 575 or J-1	None	—	Alloy 11 M126	—	38,000	Press forgings requiring moderate strength. Do not weld
Forgings, AM588 or C-1 .....	AM588 or C-1	11321	—	Alloy 8 M126	—	43,000	Simple press forgings requiring high strength. Do not weld
Rivets .....	—	Alcoa AM568	—	Alloy 9	—	(Shear) 38,000	—

Sheet and plate.....	AM3S or M	11317 Condition A	—	M111 Alloy 11 Condition A	—	28,000 min.	Moderately stressed application requiring good weldability and maximum resistance to corrosion Parts requiring moderate strength
Tubing.....	AM-C 575 and AM057S	11318 Grade 1	—	M366 Alloy 8	—	36,000	
Tubing.....	AM3S or M	11318	—	M366 Alloy 11	—	32,000	Lightly stressed part. May be welded
Joints and related materials:							
Bitumastic.....	—	14076	—	P-21	—	—	For application over regular finish
Compound, beeswax, grease.....	—	—	—	C-88	—	—	For use in engines
Compound, rust preventive.....	—	3568	—	14-C-4 C-47	—	—	
Compound, soybean oil.....	—	—	—	—	—	—	
Enamel, aircraft, glyceryl phthalate.....	—	3-98	—	E-5	—	—	
Filler, wood, liquid.....	—	3-90	—	52F1	—	—	
Par-Al-Ketone.....	—	—	—	M367	RM-61 Type A	—	Laminated; for use in engines only
Par-Al-Ketone.....	—	—	—	RM-61 Type B	—	—	Leaded, for general use on ferrous and non-ferrous metals
Powder, aluminum bronze.....	—	TT-A-476 Type B	—	RM-137-1 Type 1	—	—	
Paste, aluminum bronze.....	—	TT-A-466 Type B	—	RM-137-1 Type 11	M330 Type B	—	Albron No. 1571 or equivalent
Primer, metal, zinc chromate.....	—	14080	3-156	P-27	—	—	Volatile mineral spirits, Varnolene, etc.
Thinner, paint.....	—	TT-T-291	—	RM-103	—	—	For floats
Toluene thinner (Toluene).....	—	50-11-38	—	RM-111e-1 V-10	—	—	Clear and pigmented
Varnish, aircraft, Bakelite.....	—	—	—	V-11	52Y14	—	Anodic process
Varnish, aircraft, glyceryl phthalate.....	—	TT-V-121	3-136 L-8	—	—	—	
Lacquer, cellulose nitrate.....	—	—	—	—	—	—	
Processes:							
Anodizing—aluminum and aluminum alloys.....	—	AN-QQ-A 696	98-20005	PT-19	SR-19	—	
Application of fabric to airfoil surfaces.....	—	98-24108 AN-QQ-P-421	— 20006	SR-63 PP-1	SC-27 46P1 NAF PP-1	—	
Cadmium plating.....	—	—	—	—	—	—	

## CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S.A.E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Cleaning metal parts for finishing.....	—	98-20007	—	SR-15	—	—	
Doping aircraft surfaces.....	—	98-24100	—	SR-70	—	—	
Magnetic inspection of metals (process and application).....	—	AN-QQ-M-181	20012	EPS-1005	SR-80	—	
Finishing corrosion-resistant steel.....	—	None	—	SR-39	—	—	SA-8 for castings only
Heat treatment for non-ferrous metals.....	—	98-10026	—	SR-83 and NAF SA-8	AP-20 AP-21	—	
Insignia for naval aircraft.....	—	98-10025	—	PH-5	—	—	
Installation of transparent plastic.....	—	98-24102	—	SR-2	—	—	
Marking for naval aircraft.....	—	None	—	NAF P-1-4	—	—	
Porosity treatment—aluminum castings.....	—	98-24105	—	SR-2	—	—	Sodium-silicate process
Protective finishes.....	—	57-72-3	20002	PT-10	—	—	
Springs, manufacturing specifications for.....	—	3-100	—	SR-15	M149	—	40032 Army specification is for heat-treated springs only. Navy specification 49S7 for landing-gear springs only, and 49S8 Navy specification for all other miscellaneous springs
	—	98-40092	—	49S7a 49S8	—	—	
Removing welding flux, from aluminum fuel and oil tanks.....	—	98-20007	—	PT-5	—	—	
Terminals, cable, spliced.....	—	98-25515	—	NAF PS-2	—	—	Flexible and extra flexible Flexible 7 × 7 cable
Terminals, cable, soldered.....	—	98-25513	—	—	—	—	
Anodizing of magnesium-base alloys.....	—	None	—	PT-13	—	—	
	—	None	—	PT-13	—	—	
Dichromate treatment for magnesium-base alloys.....	—	98-20010	—	None	—	—	





CONDENSED INDEX OF SPECIFICATIONS.—(Continued)

Title	S. A. E. specification	Army		Navy		Army and/or Navy tensile strength	Remarks
		Current	Superseded	Current	Superseded		
Canvas, cotton.....	—	—	—	24C8	—	—	—
Tape, cotton, reinforcing.....	—	AN-DDD-T-91	6-83	AN-DDD-T-91	27T13	—	—
Tape, surface.....	—	6-62	—	27T14	27T12	—	—
Thread, cotton, machine sewing No. 15/16.....	—	V-T-276	—	Type 1	49T3	—	—
Thread, cotton, hand sewing, No. 5/16.....	—	Type 1B1	—	Class A	—	—	—
Thread, linen.....	—	V-T-276	—	V-T-276	—	—	—
Webbing, cotton.....	—	Type 111B	—	—	—	—	—
Transparent material (fire resistant):	—	V-T-291	15-8	V-T-291	49T4	—	Hand sewing. Desired size must be specified
Plexiglas or lucite.....	—	Type B	—	Type B	—	—	Color and type must be specified on drawings
6-185	—	—	—	None	—	—	—
94-12014	—	—	—	P-41	—	—	For cabin enclosures, inspection windows, etc.
Grade A	—	—	—	—	—	—	—
None	—	—	—	—	—	—	—
None	—	—	—	—	—	—	—
None	—	—	—	—	—	—	—
Aluminum—1 per cent zinc.....	—	—	—	A-25	—	—	—
Brass, spring.....	—	QQ-W-321	57-218	None	—	—	For metal spray
Grade C	—	—	—	—	—	—	—
Bronze, phosphor spring.....	—	QQ-W-401	57-221	22W5	—	—	—
Brass, soft lockwire.....	—	QQ-W-321	11056	Commercial	—	—	—
Grade A	—	—	—	—	—	—	—
Steel, soft lockwire.....	—	AN-QQ-W-435	48-19	AN-QQ-W-435	22W-10	—	Music wire, light-duty spring; specify on drawings, "Temper at 600°F. after forming"
Grade B	—	—	—	—	Grade B	—	—
10293	—	—	—	—	—	—	—
48-26	—	—	—	22W11	—	—	—

Steel, Cr-Va high-carbon bar...	—	AN-QQ-S-687	—	46831 Type 1 Cr-Va	—	—	Heavy-duty springs for oleos, etc. Manufacturing specification Army 40092, Navy 4987 and 4988 Corrosion resistant. Slightly mag- netic Non-ferrous; for gas-welding of 2S
Steel, spring.....	—	48-37 Type 2 QQ-R-571 Grade D	10299	22W13 Condition A PW-2	—	—	40092, Navy 4987 and 4988 Corrosion resistant. Slightly mag- netic Non-ferrous; for gas-welding of 2S
Welding, aluminum.....	—	QQ-R-571 Grade D Type E	57-204-1	PW-2	—	—	Non-ferrous; for gas-welding of 2S
Welding, Al-Si.....	—	None 10286 Grade 1G	57-204-1	PW-2	—	—	Non-ferrous; for gas-welding of aluminum alloys other than 2S
Welding, Cr-Ni.....	—	None 10286 Grade 1G	46R2 QQ-W-351 Grade E	R-16 46R4 Grade GA	22W7 Grade E	—	Stainless 18-8 with columbium Carbon rod
Welding, ferrous.....	—	10286 Grade 3G	—	—	—	—	For corrosion-resistant rod
Wire and welding rod; Ni-Cr- Fe Inconel weld wire.	—	57-174 Type 4 Class B	—	46R6	—	—	Non-magnetic. For exhaust-sys- tem parts
Wheels:	—	26258	—	None	—	—	Type 1, streamline Type 2, smooth contour Smooth contour
Aircraft landing.....	—	26272	—	None	—	—	Type 1, streamline Type 2, smooth contour Smooth contour
Wood:	—	82-3 15056 82-1	15024	39A2 39B5 None	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Ash.....	—	82-3 15056	15024	39A2 39B5 None	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Balsa.....	—	82-1	15048	AN-NN-P-511	39P13	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Maple.....	—	82-1	15048	AN-NN-P-511	39P13	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Plywood.....	—	AN-NN-P-511	82-6	AN-NN-P-511	39P13	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Plywood planking (2-ply diag- onal).....	—	15057	—	None	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Specify gravity of woods.....	—	82-4	—	None	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Spruce.....	—	82-2	15021	39S3	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft
Glue, casein.....	—	3-152	—	52G8	—	—	Water-resistant glue for use in manufacture of wooden parts for aircraft

NOTE: Remarks on welding refer to gas welding.

## CHAPTER II

### CHARACTERISTIC METHODS FOR STAMPING IDENTIFICATION OF AIRCRAFT PARTS

Stamping identification of aircraft parts, when possible, is a practical requirement observed by every manufacturer. Because of the many small detail parts and subassemblies, replacement in field service definitely demands a means of identification for repair. Identification in manufacture provides the inspection sections with a sequence of assembly and a ready reference to drawing requirements. There are, however, many points to be considered in the marking of aircraft parts; these are taken up in detail in the following paragraphs.

#### MARKING IN GENERAL

The following procedure for the stamping of parts for production and spare-parts orders is characteristic of the methods adopted by various aircraft manufacturers. Variations from a set practice, of course, must be made to conform to circumstances and requirements.

Usually, all parts of assemblies except the following have the part number stamped thereon:

1. Those parts not having a suitable surface for the part number.
2. Parts permanently assembled by welding, brazing, soldering, or riveting.
3. Highly stressed parts that cannot be stamped without affecting the strength of the part.
4. Aluminum and aluminum-alloy parts manufactured from 0.032 Army or 0.040 Navy gauge or thinner.

Extreme care should be taken in stamping material above 0.032 to prevent distortion of the part. It is best that the stamping of the part number be applied on interior surfaces of the exterior sheeting. Never apply the part number on a chafing area.

Large assemblies, such as wings, etc., usually bear the assembly number stamped on a suitable aluminum strip or a satisfactory name plate, and the strip or name plate is attached to its respective unit with Parker Kalons (Parker Appliance Co., Cleveland, Ohio). The location of the strip or name plate should be such as to permit its being seen after final assembly of the unit, making identification easy for both inspection and replacement requirements.

Sheet stock for fillets, doors, and the like requiring trimming in various assembly departments should be stamped by the fabricating department by means of a rubber stamp in such a location that in subsequent operations the ink-stamp marks will not be obliterated.

All parts should bear the required inspection-acceptance stamps. Sheet stock under 0.032 Army and 0.040 Navy are usually rubber-stamped. For material above 0.032, metal stamps may be used.

The following are recommended to be stamped 100 per cent:

1. Parts routed to final assembly and/or shipping departments.
2. Parts similar to other parts, where identification may be confused.

### BOLT IDENTIFICATION

The proper identification of bolts, whether standard, reworked, or special, is important. In many cases, proper identification of material as well as of type governs controlling factors of strength as well as corrosion-fatigue selection.

1. All AN standard steel bolts that are reworked from regular standard bolts, such as shortening the thread length, drilling the head for safety wiring, cutting the shoulder on the thread, etc., usually have a circle circumscribed around the standard asterisk—*e.g.* \*—as a means of identification.

2. Reworked AN standard aluminum-alloy bolts may be identified by the lettering "SPEC," stamped on the head of the bolts.

3. Special bolts should have the part number gang-stamped on the head of the bolt, provided that the diameter of the head is not smaller than 1 in. Part numbers should never be stamped on the sides of bolt-heads. This applies not only to bolts that are obviously dimensionably non-standard but to bolts of special material, high-tensile heat treatment, etc., as well. Where it is not practicable to do this, as in the case of a very small bolthead that would not allow the use of the gang stamp, the bolthead should be stamped "SPEC."

4. The letter X or asterisk \* may be used as identification on the heads of nickel-steel boltheads treated to 125,000 to 145,000 p.s.i. requirements.

5. Corrosion-resistant steel bolts and those made from chrome-molybdenum steel are special bolts and should be stamped as specified in the discussion on special bolts.

6. Bearing bolts are usually stamped with the letter B, when coded, to indicate that the plating has been removed from the bearing surface (if this is true).

7. Most drawings specify the stamping for boltheads. Where this is not covered, the preceding information should constitute a basis for procedure.




When drawings specify hardness readings for heavy dural parts, steel fittings, etc., the parts, after Rockwell or Brinell, might be stamped with a circled  $\oplus$  to indicate that the parts have been hardness-tested and are within the limits set forth on the drawing.

### SPARE PARTS

The following procedure, suggested for the handling of spare parts with reference to stamping part numbers, will materially reduce the time consumed in handling:

1. All detail parts and assemblies should be stamped with the part number as well as the required inspection stamps.

2. If parts cannot be stamped because material is too thin or if the parts are so fabricated as to make stamping impracticable, metal tags should be used. A suggested procedure is as follows:

- a. On orders calling for one to eight parts, one tag for each part should accompany the order.
  - b. When there are more than eight parts, eight tags should be sent along with the parts, regardless of the quantity above eight.
  - c. Tags should bear the correct part number and should also carry the required inspection or acceptance stamps.
  - d. With the exception of acceptance stamps, *part numbers or special stamps* should be affixed prior to submitting parts for inspection.
  - e. Subassemblies should, if possible or practicable, be stamped with the part number and acceptance stamps.
  - f. Parts too small for individual wrapping, normally shipped in containers, cartons, or cloth bags, need not be identified individually. The containers, however, should be properly marked with a tag bearing all the necessary information. Parts that can be threaded on a wire may be identified by a metal tag attached to the wire.
3. a. All parts that receive magnetic inspection may be stamped with an MF outlined within an oval: ; a rectangle: ; or a square: . Care should be exercised in placing the stamp mark in a location where subsequent operations will not obliterate the MF.
- b. Bolts, small fittings, and other parts too small to be stamped should be color-identified by some permanent means.
  - c. Magnetically inspected AN bolts should not be stamped individually. Magnetic inspection stamps should appear on the package or container, or the heads may be marked with a selected color-stamping pad.

As mentioned, the system and procedure described above suggest a characteristic method, but it should be modified to fit the particular manufacturing system involved.

### CHARACTERISTIC COLOR-CODE IDENTIFICATION OF FERROUS AND NON-FERROUS METAL-STOCK COMPOSITION

The color marking of ferrous and non-ferrous metal stock may be accepted as an absolute requirement by government procurement agencies. The reason for such marking is plainly obvious to those

acquainted with the aircraft industry. Material identification of metal composition is important to the production safety of the airplane or part. The necessity of providing the right material to conform with design, information, and drawings is important to production planning, etc.

Every manufacturer has his own method and procedure of and necessity for each color identification. Therefore, in the paragraphs that follow, the information offered is given only as a suggested method for identification. It is important for the manufacturer to set a group of colors as standard and to adhere to them to prevent confusion. It is also important that the color decided upon does not conflict basically or in combination.

There are many methods adaptable to the identification of the stock, the most popular being the roller stamp, with identifying characters using the singular color for application. Otherwise, the colors are applied in stripes, as explained in the following paragraphs. If rubber-stamp marking is done and inks in the colors selected are used, the inks should be of the non-phenolic type.

In order to prevent excessive cleaning of material marking, the following is suggested.

Color identification should be omitted from:

1. Aluminum and aluminum alloy.
  - a. Tubing.
  - b. Sheet.
  - c. Extrusions.
2. Corrosion-resistant steel.
  - a. Tubing.
  - b. Sheet.

The preceding materials are to be rubber-stamped (aluminum alloy and corrosion steel).

In color-marking locations, apply color identification stripes along the entire length of bars, rods, shapes. For bar diameters less than 1 in. or in sizes where there are odd shapes or no shape or flat surfaces not easily accessible to marking, apply stripes to the two extremes within 2 ft. of the middle of the piece.

Colors for color coding are:

Number	Colors
1	Willow green
2	True blue
3	Insignia red
17	White
4	Lemon yellow
5	Maroon
6	Cream
7	Olive drab

umber	Colors
8	Engine gray
9	Insignia blue
10	Pink
11	Black
12	International orange
13	Orange-yellow
14	Aircraft gray
15	Aluminum
16	Antique bronze

These colors are taken from the "AN Porcelain Color Standards" and are carried in stock by most paint manufacturers.

SUGGESTED CHART FOR APPLICABLE COLORS: FOR AIRCRAFT FERROUS AND  
NON-FERROUS METALS

S.A.E.	Materials	Color stripe	
	Carbon tool steel	No. 1 green	No. 9 blue
	Cobalt high-speed tool steel	1 green	15 aluminum
	Tungsten high-speed tool steel	17 white	14 gray
	Tungsten-alloy chisel steel	1 light green	11 black
	Oil-hardening (non-deforming) steel	1 light green	5 maroon
	High-carbon, high-chrome steel	10 pink	8 gray
1010	Carbon steel	17 white	5 maroon
1015	Carbon steel	17 white	3 red
1020	Carbon steel	2 blue	
X1020	Carbon steel	1 green	
1025	Carbon steel	17 white	6 cream
X1025	Carbon steel	1 green	14 gray
1030	Carbon steel	1 white	11 black
1035	Carbon steel	14 gray	8 gray
1040	Carbon steel	17 white	10 pink
1045	Carbon steel	17 white	12 orange
1050	Carbon steel	17 white	15 aluminum
1055	Carbon steel	13 orange	3 red
1060	Carbon steel	13 orange	9 blue
1065	Carbon steel	13 orange	1 green
1070	Carbon steel	13 orange	12 orange
1075	Carbon steel	13 orange	4 yellow
1080	Carbon steel	16 bronze	7 olive drab
1085	Carbon steel	1 green	2 blue
1090	Carbon steel	13 orange	17 white
1095	Carbon steel	13 orange	
1112	Free-cutting steels	3 red	6 cream
X1112	Free-cutting steels	9 blue	
1115	Free-cutting steels	3 red	8 gray
1120	Free-cutting steels	3 red	2 blue
X1314	Free-cutting steels	7 olive drab	13 orange
X1315	Free-cutting steels	1 green	7 olive drab
X1330	Free-cutting steels	15 aluminum	8 gray
X1335	Free-cutting steels	3 red	4 yellow
X1340	Free-cutting steels	3 red	10 pink
T1330	Manganese steels	15 aluminum	11 black
T1335	Manganese steels	15 aluminum	4 yellow
T1340	Manganese steels	10 pink	12 orange
T1345	Manganese steels	15 aluminum	12 orange
T1350	Manganese steels	15 aluminum	3 red
2015	Nickel steels	9 blue	16 bronze
2115	Nickel steels	3 red	14 gray
2315	Nickel steels	9 blue	15 aluminum
2320	Nickel steels	3 red	9 blue
2330	Nickel steels	6 cream	16 bronze
2335	Nickel steels	9 blue	11 black
2340	Nickel steels	13 orange	6 cream
2345	Nickel steels	9 blue	12 orange
2350	Nickel steels	13 orange	11 black
2515	Nickel steels	6 cream	
3115	Nickel-chromium steel	4 yellow	12 orange
3125	Nickel-chromium steel	4 yellow	14 gray
3130	Nickel-chromium steel	11 black	4 yellow
3140	Nickel-chromium steel	4 yellow	10 pink
3145	Nickel-chromium steel	7 olive drab	14 gray
3150	Nickel-chromium steel	4 yellow	8 gray



SUGGESTED CHART FOR APPLICABLE COLORS: FOR AIRCRAFT FERROUS AND  
NON-FERROUS METALS.—(Continued)

S.A.E.	Materials	Color stripe	
3220	Nickel-chromium steel	No. 14 gray	No. 9 blue
3230	Nickel-chromium steel	14 gray	6 cream
3240	Nickel-chromium steel	14 gray	10 pink
3250	Nickel-chromium steel	14 gray	15 aluminum
3312	Nickel-chromium steel	7 olive drab	9 blue
3340	Nickel-chromium steel	4 yellow	5 maroon
3435	Nickel-chromium steel	14 gray	5 maroon
4120	Chrome-molybdenum steel	10 pink	11 black
X4130	Chrome-molybdenum steel (normalized)	17 white	
X4130	Chrome-molybdenum steel (heat-treated)	13 orange-yellow	
4135	Chrome-molybdenum steel	17 white	2 true blue
4140	Chrome-molybdenum steel	2 true blue	15 aluminum
4150	Chrome-molybdenum steel	10 pink	15 aluminum
4340	Chrome-nickel-molybdenum steel	7 olive drab	
4345	Chrome-nickel-molybdenum steel	15 aluminum	
4615	Nickel-molybdenum steel	10 pink	7 olive drab
4620	Nickel-molybdenum steel	10 pink	
4640	Nickel-molybdenum steel	10 pink	6 cream
4815	Nickel-molybdenum steel	10 pink	1 light green
3325	Nickel-chromium steel	2 true blue	7 olive drab
4820	Nickel-molybdenum steel	10 pink	5 maroon
5120	Chromium steel	12 orange	11 black
5140	Chromium steel	12 orange	8 gray
5150	Chromium steel	12 orange	7 olive drab
52100	Chromium steel	12 orange	2 true blue
6115	Chrome-vanadium steel	11 black	8 gray
6120	Chrome-vanadium steel	11 black	16 bronze
6125	Chrome-vanadium steel	11 black	7 olive drab
6130	Chrome-vanadium steel	5 maroon	15 aluminum
6135	Chrome-vanadium steel	5 maroon	13 orange-yellow
6140	Chrome-vanadium steel	5 maroon	3 red
6145	Chrome-vanadium steel	5 maroon	
6150	Chrome-vanadium steel	11 black	
6195	Chrome-vanadium steel	5 maroon	12 orange
71360	Tungsten steel	5 maroon	11 black
71660	Tungsten steel	9 blue	8 gray
7260	Tungsten steel	2 true blue	5 maroon
9255	Silicon manganese steel	2 true blue	13 orange-yellow
9260	Silicon manganese steel	13 orange-yellow	16 bronze
30905	Corrosion and heat-resisting alloys	4 yellow	
30915	Corrosion and heat-resisting alloys	6 cream	11 black
51210	Corrosion and heat-resisting alloys	6 cream	12 orange
X51410	Corrosion and heat-resisting alloys	6 cream	1 light green
51335	Corrosion and heat-resisting alloys	6 cream	15 aluminum
51510	Corrosion and heat-resisting alloys	6 cream	9 blue
51710	Corrosion and heat-resisting alloys	6 cream	7 olive drab
N135	Type G nitralloy	4 yellow	9 blue
	Nickel cast iron	7 olive drab	3 red
	Armco magnetic iron	12 orange	3 red
	Ticon copper-molybdenum iron	17 white	9 blue

Alcoa	Dow chemicals	Non-ferrous	Color stripe	
2S	—	Aluminum	No. 5 maroon	No. 9 blue
3S	—	Aluminum alloy	8 gray	
4S	—	Aluminum alloy	13 orange-yellow	15 aluminum

SUGGESTED CHART FOR APPLICABLE COLORS: FOR AIRCRAFT FERROUS AND  
NON-FERROUS METALS.—(Continued)

Alcoa	Dow chemicals	Non-ferrous	Color stripe	
13	—	Aluminum alloy	No. 16 bronze	
14ST	—	Aluminum alloy	3 red	No. 16 bronze
17ST	—	Aluminum alloy	3 red	
17ST AL	—	Aluminum alloy	7 olive drab	8 gray
24SO	—	Aluminum alloy	2 true blue	9 blue
24SO AL	—	Aluminum alloy	6 cream	8 gray
24ST	—	Aluminum alloy	12 orange	
24ST AL	—	Aluminum alloy	2 true blue	14 gray
43	—	Aluminum alloy	2 true blue	8 gray
51SW	—	Aluminum alloy	2 true blue	6 cream
52S	—	Aluminum alloy	6 cream	4 yellow
53SW	—	Aluminum alloy	2 true blue	16 bronze
61SW	—	Aluminum alloy	1 light green	16 bronze
195	—	Alloy HT	15 aluminum	7 olive drab
220T4	—	Aluminum alloy	2 true blue	4 yellow
355T6	—	Aluminum alloy	17 white	8 gray
356	—	Aluminum alloy	2 true blue	11 black
	E	Magnesium alloy	10 pink	9 blue
AM52S	F	Magnesium alloy	17 white	16 bronze
AM 3S	M	Magnesium alloy	13 orange-yellow	14 gray
57S	JS-1	Magnesium alloy	12 orange	16 bronze
AM53S		Magnesium alloy	10 pink	2 true blue
AMC57S	J-1	Magnesium alloy	8 gray	5 maroon
AM230	K	Magnesium die-cast alloy	5 maroon	6 cream
AM263	R	Magnesium die-cast alloy	5 maroon	7 olive drab
AM265	H	Magnesium die-cast alloy	5 maroon	16 bronze
AM748	X	Magnesium sand-cast alloy	13 orange-yellow	8 gray
		Inconel	7 olive drab	4 yellow
		Brass	14 gray	
		Naval brass	3 red	
		Phosphorous bronze	4 gray	12 orange
		Commercial bronze—90 cu. 10 zn.	4 gray	11 black
		Aluminum bronze (Type B)	3 red	11 black
		Manganese bronze	16 bronze	15 aluminum
		Gun metal	4 yellow	16 bronze
		Manganese bronze (HT)	7 olive drab	17 white
		Monel metal	17 white	4 yellow
		—	Stamp hardness in No. 11 black	
		Copper		



PART II

AIRCRAFT METALS IN PRODUCTION



## CHAPTER III

### ALUMINUM AND ALUMINUM ALLOYS

Aviation owes much to the development and adoption of the metal aluminum. Aviation owes still more to the metallurgists for their research in the alloy field. For although aluminum presented to aircraft manufacturers the answer to their need for strength in a metal without the taxation of excess weight, this strength did not include the type found in the heavier metals. The metallurgist, by research, alloyed the valuable weight-saving aluminum with small amounts of copper, silicon, manganese, zinc, nickel, chromium, etc., in order to bolster the strength. Typical amounts of these alloys can be found in Table 1.

TABLE 1.—CHARACTERISTIC COMPOSITION OF WROUGHT-ALUMINUM ALLOYS\*

Alloy	Percentage of alloying elements—aluminum and normal impurities constitute remainder								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
3S	—	—	1.2	—	—	—	—	—	—
11S	5.5	—	—	—	—	—	—	0.5	0.5
14S	4.4	0.8	0.8	0.4	—	—	—	—	—
17S	4.0	—	0.5	0.5	—	—	—	—	—
A17S	2.5	—	—	0.3	—	—	—	—	—
18S	4.0	—	—	0.5	—	2.0	—	—	—
24S	4.5	—	0.6	1.5	—	—	—	—	—
25S	4.5	0.8	0.8	—	—	—	—	—	—
32S	0.9	12.5	—	1.0	—	0.9	—	—	—
A51S	—	1.0	—	0.6	—	—	0.25	—	—
52S	—	—	—	2.5	—	—	0.25	—	—
53S	—	0.7	—	1.3	—	—	0.25	—	—
56S	—	—	0.1	5.2	—	—	0.1	—	—
61S	0.25	0.6	—	1.0	—	—	0.25	—	—
70S	1.0	—	0.7	0.4	10.0	—	—	—	—

\* Heat-treatment symbols have been omitted, since composition does not vary for different heat-treatment practices.

Aircraft aluminum and its alloys can be divided into two classifications:

1. Wrought alloys.
  - a. Alclad products.
  - b. Forgings.

- c. Impact extrusions.
  - d. Extruded shapes.
  - e. Screw-machine products.
2. Cast alloys.
- a. Sand castings.
  - b. Sand castings heat-treated.
  - c. Permanent mold castings.
  - d. Die castings.

Wrought-aluminum alloys are seldom alloyed more than 6 to 7 per cent. Additional strength is given to the metal by heat treatment which is taken up in detail in the following chapters of this book. Appreciable increase in tensile yield strength and hardness results from this process. Therefore, by alloying the pure aluminum and by heat treatment, there has been made available to the airplane designer and manufacturer a series of aluminum alloys having the approximate strength of steel without the disadvantages of its weight.

Although this book is not concerned with detailed structural information, it is intended to include detailed description of the structural characteristics of materials.

Rather than transfer cumulative information, the following edited information is quoted from "Alcoa, Aluminum and Its Alloys," published by the Aluminum Co. of America (1940).

### PHYSICAL PROPERTIES

**Specific Gravity.**—Aluminum of commercial purity weighs 0.098 lb. per cubic inch, corresponding to a specific gravity of 2.71. Data for the Alcoa wrought alloys are shown in Table 5 and for the cast alloys, in Table 2. For purposes of approximation, it may be remembered that aluminum, including its alloys, weighs  $\frac{1}{10}$  lb. per cubic inch.

**Electrical Conductivity.**—Aluminum has a high electrical conductivity; the manufacture of cable and bus bar for the transmission of electric power constitutes one of the large uses of the metal. This property is lowered by the addition of other metals, the amount of the reduction varying with the nature and amount of the added element. Practically pure aluminum has a volume conductivity in excess of 64 per cent of the International Annealed Copper Standard, but because of its low specific gravity, the mass conductivity is more than 212 per cent. Commercial aluminum conductors are made from aluminum of such purity that the conductivity is not less than 61 per cent. The values for the wrought alloys of Alcoa aluminum are shown in Table 5 and for the cast alloys of Alcoa aluminum, in Table 6.

Elements in solid solution cause much greater decrease in electrical conductivity than when they are present as undissolved constituents.

Alloys containing hardeners, which, like silicon and copper, change greatly in solid solubility with rise in temperature, show corresponding variations in conductivity, depending on their rate of freezing and previous thermal treatment. This fact should be considered particularly in the case of castings supplied in the "as cast" condition.

**Thermal Conductivity.**—Aluminum of a purity of 99.6 per cent has a thermal conductivity of 0.52 in c.g.s. units (calories per second per square centimeter per centimeter of thickness per degree of centigrade), which is equivalent to 1509 B.t.u. per hour per square foot per inch of thickness per degree Fahrenheit. The thermal conductivities of some of the aluminum alloys are shown in Tables 5 and 6.

**Thermal Expansion.**—The coefficient of thermal expansion of aluminum is slightly more than that of pure aluminum, except in those aluminums that contain relatively high percentages of silicon, in which the value is appreciably lowered. In spite of the difference in expansion under subjection to thermal changes, composite structures of steel and aluminum alloys show entirely satisfactory performance.

**Modulus of Elasticity.**—Young's modulus, which is the ratio of stress to strain in the elastic range, is approximately the same in aluminum and its commercial alloys. The average value for this constant is approximately 10,300,000 p.s.i. The value may be increased somewhat by relatively large additions of alloying elements. In fact, careful measurements in 24S\* alloy have given an average close to 10,500,000 p.s.i.

Because of the lower value of this constant as compared with that of steel, it is necessary to use deeper sections in aluminum alloys in order to maintain the same deflection characteristics when they are loaded as beams. Such redesign can be accomplished to produce a structure having the same deflection under load and actually higher ultimate strength than would be obtained with structural steel and, at the same time, to realize a saving in weight of more than a pound for each pound of aluminum alloy used.

The lower modulus of elasticity is an asset when impact loads are to be resisted, since, other things being equal, the lower the modulus the greater the ability to absorb energy without permanent set. The lower modulus is also advantageous in reducing stresses produced by misalignment, settlement of supports, or other fixed deflections, accidental or intentional.

The modulus of rigidity is 3,850,000 p.s.i. for aluminum and its commercial alloys, corresponding to a value of 0.33 for Poisson's ratio.

**Mechanical Properties.**—Typical average mechanical properties of aluminum (2S) and of the various wrought alloys of Alcoa aluminum are shown in Table 5. These values may be used in comparing the alloys with each other or with other materials, since typical properties are commonly quoted.



Purchase specifications are based on the minimum values for those properties that are regularly determined in the routine control of commercial manufacturing operations. Tables showing these minimum properties that can be guaranteed are included in the following pages.

It will be observed that the minimum properties guaranteed for an alloy are not the same in all commodities or in all sizes of a given product. Since the type and dimensions of the test specimen specified by standard

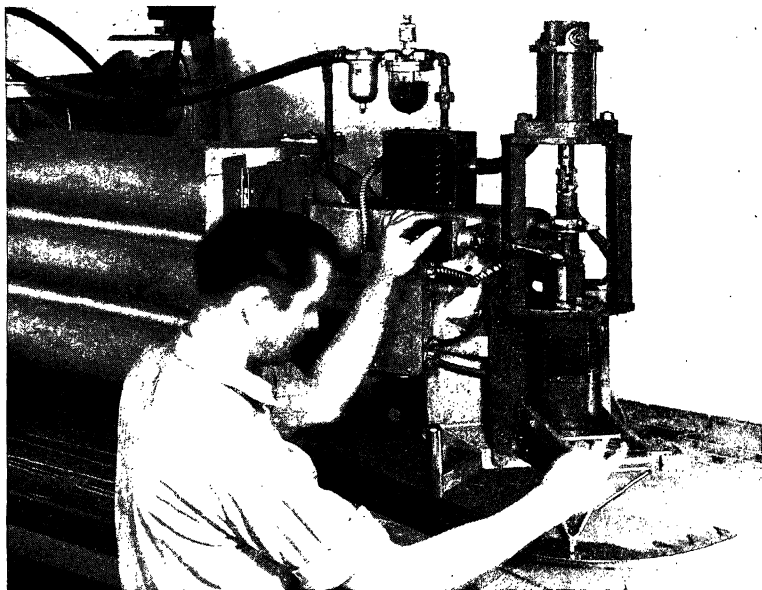


FIG. 1.—A routing machine for cutting aluminum-alloy contours. (Soluble cutting oil vehicle with water.)

testing practices vary with the nature of the product or with its dimensions, some of the variations in the guaranteed properties represent differences inherent in the test rather than fundamental differences in the properties of the metal in the various commodities. In the case of rod that is tested in full section, the elongation is measured over a gauge length equal to four times the diameter of the rod in order to compensate for the effect of variations in the cross section of the test specimen.

The commonly used method of straightening or flattening materials by stretching causes a substantial increase in the tensile yield strength in the direction of the applied stress. There is comparatively little change in the properties as measured at right angles to the direction of stretching. There is also a much smaller change in the compressive yield strength of

the material. The properties guaranteed for sheet are determined at 90 deg. to the direction of stretching (except in intermediate tempers of the softer alloys). The minimum yield strengths of tubing, shapes, and bar are specified conservatively on the basis of the tension-test results, if the known relation to the compressive properties is taken into account.

**Effect of Temperature on Mechanical Properties.**—In common with other materials, the tensile strength, yield strength, and modulus of elasticity of aluminum alloys are lower at elevated temperatures than they are at ordinary temperatures. The elongation usually increases as the temperature is raised until, at a temperature a little below the melting point, it drops nearly to zero. This corresponds to the "hot-short" range of the metal.

Tests made at  $-114^{\circ}\text{F.}$  show strengths and elongations higher than those obtained at ordinary temperatures.

### CHEMICAL PROPERTIES

The resistance of aluminum to the attack of a variety of chemicals is explained by its property of forming a thin, firmly adherent coat of oxide over its surface, which prevents further action.

A number of commercial chemicals are produced, stored, or shipped in aluminum equipment. Concentrated nitric and acetic acids used in the textile industry are handled in aluminum, not only because the life of the metal is long but also because any compounds introduced by superficial attack are colorless. For the same reasons, gums and resins used in clear varnishes and lacquers are processed in aluminum.

Aluminum tank cars make possible bulk shipments of concentrated solutions of hydrogen peroxide, because its decomposition is not catalyzed by aluminum compounds.

Numerous fermentation reactions are carried out in aluminum equipment, because aluminum compounds do not poison the yeasts or other organisms that cause the reaction to proceed.

The resistance of aluminum to attack and the fact that its salts have no harmful action on the human system account for the wide use of aluminum in the processing and preparation of foods and beverages.

Strong alkalis dissolve aluminum oxide as well as the metal and thus remove the protective film from its surface, permitting chemical action to proceed till the metal is destroyed. However, many solutions having a mildly alkaline reaction are used successfully in contact with aluminum, particularly if an inhibitor is present. Many moderately alkaline washing powders and metal cleaners are marketed with additions of sodium silicate, which make them safe for use in contact with aluminum.

Gaseous compounds of sulphur are without harmful action on aluminum. The successful use of the metal for architectural purposes in

industrial centers gives evidence of this fact. Similarly, much of the equipment in plants for the manufacture of rayon is of aluminum, because of its resistance to attack by compounds of sulphur that are very harmful to most commercial metals. In both these applications, the fact that the compounds formed by superficial action are colorless is of outstanding importance.

Use is made of the chemical properties of aluminum in the deoxidation of molten steel and in the reduction of some of the refractory oxides to produce metals such as vanadium. Advantage is taken of the high heat of reaction of aluminum in reducing iron oxide in the Thermit welding process.

**Resistance to Corrosion.**—The resistance of a material to corrosion is relative and depends on a comparison with other metals or with other alloys of the same metal. None of the commercial metals is immune to all conditions to which structural materials are exposed. There is always the possibility of overstressing the dangers of corrosion, with the result that the prospective user is deterred from employing the metal where there is no occasion for concern. On the other hand, if the possibility of trouble is ignored, metal failures may result that could have been avoided by simple protective measures.

Commercial aluminum contains, as a maximum, 1 per cent of impurities. This metal, designated 2S in the wrought condition, is widely used because of its high resistance to ordinary conditions of exposure. Selected grades of higher purity are even more resistant to most forms of attack. The addition of other elements to produce alloys from commercial aluminum does not usually improve the resistance of the metal and in most cases causes some loss in this property. Magnesium, manganese, and chromium have no adverse effect; and silicon has little.

All the commercial aluminum alloys are properly classed as materials resistant to corrosion, although some are more resistant than others and hence are chosen for those applications in which this property is of major importance.

Alloy 3S has practically the same resistance as 2S to the atmosphere and to salt water. Alloy 52S appears to be more resistant to salt water than 2S, from the standpoint of the retention of both its mechanical properties and its appearance.

Considerable study has been made on the effect of the temper of these alloys and their resistance to attack. In general, it may be stated that any differences in this property as a result of strain hardening are less than the small differences that are normally to be expected from one lot to another of commercial materials.

These alloys are generally used without any protection other than the usual precaution to avoid electrolytic action from contact with a dis-

similar metal. Under severe conditions of exposure, such as may prevail with wood or other absorbent material in the presence of moisture, protective paint coatings are desirable as an added precaution.

Of the heat-treatable alloys, 53S is the most resistant, being equal to 2S in its resistance to industrial atmospheres and to salt spray but being

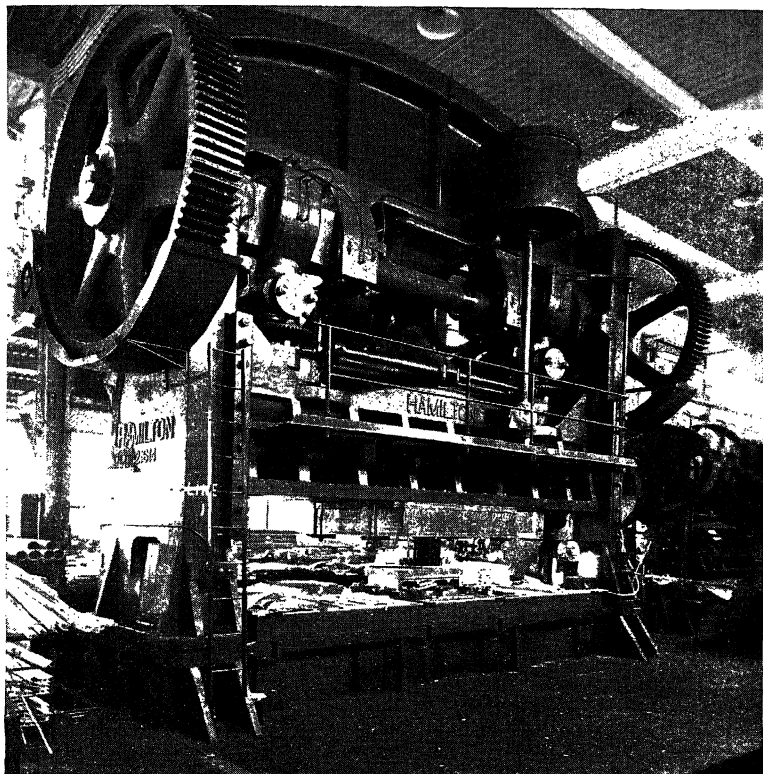


FIG. 2.—A mechanical Hamilton press used in deep-drawing operation on aluminum alloys.

less resistant to some chemicals. Under atmospheric exposure, there is little to choose between 53S and 61S; in salt water or salt spray, 61S shows somewhat more attack, although both these alloys are definitely more resistant than 17S or 24S. Also, in contrast with the latter alloys, resistance to attack is substantially the same in all tempers ("O," "W," and "T") and even when they are quenched slowly during heat treatment, there is a minimum of harmful effect.

Both 17S and 24S, although more susceptible to losses in mechanical properties when exposed to the weather than are 53S and 61S, are still to be classed as resistant materials. Tests of standard structural shapes of 17S alloy showed no significant loss in tensile properties after exposure on the seacoast for 1 year. Specimens taken after 1 year indicate that the attack tends to be self-stopping.

In the design of aircraft, where reduction of weight is reflected in improved performance, thin sections must be used with minimum factors of safety. Protective systems including anodic treatment, Zinc Chromate Primers, and aluminum-type paints have been developed that make the maintenance of airplanes built of 24S alloy a relatively simple matter. It should be pointed out that the resistance to corrosion normally exhibited by 17S-T and 24S-T depends upon the observance of the recommended methods of heat treatment. These alloys are never used in the annealed temper because of their inferior mechanical properties and resistance to corrosion in that temper. A rapid quenching from the heat-treatment temperature is necessary to develop the desired resistance to corrosion, even though a slower quenching may produce the specified physical properties. Similarly, the resistance of these alloys to corrosion is lowered if they are heated after quenching. For that reason, hot-forming, hot-riveting, and welding processes are not recommended unless the assembly can be subsequently heat-treated.

Among the cast alloys, there are similar differences in resistance to corrosive environments. Under most exposures, the alloys in which magnesium is the alloying agent (214 and 220 and die-cast alloy 218) show the least attack. Only slightly less resistant are the alloys in which silicon or silicon and magnesium are the hardening elements: 43, 47, 356, B214, and die-cast alloy 13. The alloys in which copper or nickel are present in substantial percentages show less resistance to severely corrosive environments.

Although all the aluminum alloys in commercial use are resistant to corrosion, they are not all equally resistant. Whether they should be given protection treatment depends upon the alloy and the type of service that it is to perform. The least resistant of these will last indefinitely in most interior applications, whereas the most resistant should be protected in certain exposures as an added precaution.

**The Significance of Tempers and Temper Designations.**—As the metal is “cold-worked,” it becomes strain-hardened. If the metal is subsequently heated to the temperature designated for annealing, the strain is relieved, and the metal returns to its “soft” temper. This temper is designated by the letter O—*e.g.*, 24SO.

A letter preceding the alloy symbol denotes a slight change in composition from the basic alloy.

One class of the alloys is hardened only by cold-working. In this class belong 2S, 3S, and 52S.

The "hard" temper is designated by the soft, or "SO," stage, and "H," or hard, stages are designated by fractions  $\frac{1}{4}$ H;  $\frac{1}{2}$ H;  $\frac{3}{4}$ H. These denote the stage of hardness from the annealed state.

The letter T following the alloy number denotes the alloy in its fully hardened and aged state. This designation is used with alloys that age-harden fully at normal room temperature.

The letter W is used with 53S and 61S type materials that require artificial aging and signifies "as quenched" hardness.

"RT" designation is assigned to the temper that results from "strain-hardening" of alloys after they have been heat-treated.

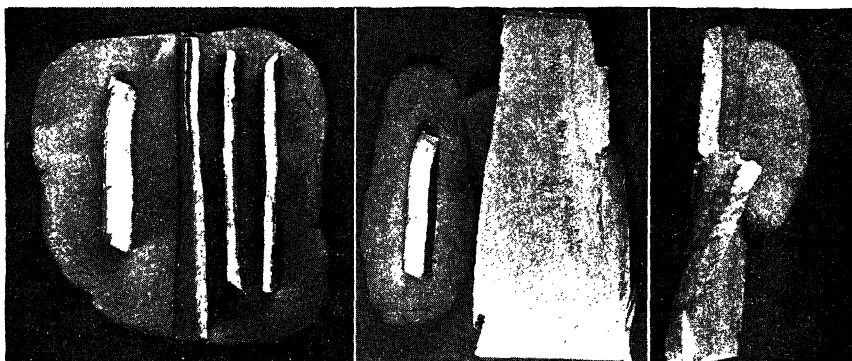


FIG. 3.—Examples of lamination and grain growth in an aluminum-alloy part due to cold-working by die stretching.

**Handling and Working Aluminum Alloys.**—There are 10 important points in the handling and working of aluminum and its alloys in production.

1. Do not bend material on a radius different from that specified on the drawing.
2. Do not bend aluminum alloy along the grain, unless specified on the pertinent drawing. Bend it as nearly at right angle as possible.
3. Do not use a scratch awl for marking material; use a soft-lead pencil.
4. Do not use ordinary layout dye on material to be used in the actual fabrication of a part or an assembly.
5. Do not scratch or scrape aluminum-alloy surfaces, either painted or otherwise (unless special permission is granted for spot-welding, etc.).
6. Do not squeeze or hammer rivets to the extent of bruising or distorting the parts being riveted.

7. Do not use 17ST rivets that have been heat-treated for longer than  $\frac{1}{2}$  hr. unless they have been properly refrigerated.

8. Do not use 24ST rivets that have been heat-treated for longer than 15 min. unless they have been properly refrigerated.

9. Do not clamp aluminum-alloy parts in a vise without using copper or aluminum false jaws. Do not fail to clean the surface of the part and the false jaws before inserting the parts in the vise.

10. Do not file welds on aluminum-alloy parts either for fit or for appearance unless specified on the drawing.

**PERTINENT DESCRIPTIVE TABLES  
FOR ALUMINUM AND ALUMINUM ALLOYS**

TABLE 2.—COMPOSITION OF ALUMINUM SAND-CASTING ALLOYS\*

Alloy	Percentage of alloying elements—aluminum and normal impurities constitute remainder						
	Copper	Iron	Silicon	Zinc	Magnesium	Nickel	Manganese
43	—	—	5.0				
47	—	—	12.5				
108	4.0	—	3.0				
112	7.5	1.2	—	2.0			
122	10.0	1.2	—	—	0.2		
142	4.0	—	—	—	1.5	2.0	
195	4.0	—	—	—			
212	8.0	1.0	1.2	—			
214	—	—	—	—	3.8		
220	—	—	—	—	10.2		
A334	3.0	—	4.0	—	0.3		
355	1.3	—	5.0	—	0.5		
A355	1.4	—	5.0	—	0.5	0.8	0.8
356	—	—	7.0	—	0.3		
645	2.5	1.2	—	11.0			

\* Heat-treated symbols have been omitted, since composition does not vary for different heat-treatment practices.

composition does not vary for different heat-treatment practices.

TABLE 3.—COMPOSITION OF ALUMINUM PERMANENT-MOLD CASTING ALLOYS\*

Alloy	Percentage of alloying elements—aluminum and normal impurities constitute remainder					
	Copper	Iron	Silicon	Zinc	Magnesium	Nickel
43	—	—	5.0			
A108	4.5	—	5.5			
B113	7.0	1.2	1.7			
C113	7.0	1.2	4.0	2.0		
122	10.0	1.2	—	—	0.2	
A132	0.8	0.8	12.0	—	1.0	2.5
138	10.0	1.4	4.0	—	0.2	
142	4.0	—	—	—	1.5	2.0
B195	4.5	—	2.5			
A214	—	—	—	1.8	3.8	
355	1.3	—	5.0	—	0.5	
356	—	—	7.0	—	0.3	

\* Heat-treatment symbols have been omitted, since composition does not vary for different heat-treatment practices.

TABLE 4.—COMPOSITION OF ALUMINUM DIE-CASTING ALLOYS

Alloy	Percentage of alloying elements—aluminum and normal impurities constitute remainder			
	Copper	Silicon	Nickel	Magnesium
13	—	12		
43	—	5		
81	7	3		
82	14	5		
83	2	3		
85	4	5		
93	4	2	4	
218	—	—	—	8



TABLE 5.—TYPICAL PROPERTIES OF WROUGHT ALLOYS

Alloy	Specific gravity	Weight, lb. per cu. in.	Electrical conductivity per cent of International Annealed Copper Standard	Thermal conductivity at 100°C., c.g.s. units
2S-O	2.71	0.098	59	0.54
2S-H	2.71	0.098	57	0.52
3S-O	2.73	0.099	50	0.45
3S- $\frac{1}{4}$ H	2.73	0.099	42	0.39
3S- $\frac{1}{2}$ H	2.73	0.099	41	0.38
3S-H	2.73	0.099	40	0.37
11S-T3	2.82	0.102	40	0.37
14S-O	2.80	0.101	50	0.45
14S-T	2.80	0.101	40	0.37
17S-O	2.79	0.101	45	0.41
17S-T	2.79	0.101	30	0.28
A17S-T	2.74	0.099		
18S-O	2.80	0.101	50	0.45
18S-T	2.80	0.101	40	0.37
24S-O	2.77	0.100	50	0.45
24S-T	2.77	0.100	30	0.28
25S-T	2.79	0.101	40	0.37
32S-O	2.69	0.097	40	0.37
32S-T	2.69	0.097	35	0.32
A51S-O	2.69	0.097	55	0.50
A51S-W or T	2.69	0.097	45	0.41
52S-O	2.67	0.096	40	0.37
52S-H	2.67	0.096	40	0.37
53S-O	2.69	0.097	45	0.41
53S-W or T	2.69	0.097	40	0.37
56S-O	2.64	0.095	29	0.28
56S-H	2.64	0.095	27	0.26
61S-O	2.70	0.098	45	0.41
61S-W or T	2.70	0.098	40	0.37
70S-O	2.91	0.105	40	0.37
70S-T	2.91	0.105	35	0.32
Brass	8.4-8.8	0.304-0.319	26-43	0.29-0.44
Copper	8.94	0.322	100	
Magnesium	1.74	0.063	38	0.37
Monel	8.8	0.318	4	0.06
Nickel	8.84	0.319	16	0.14
Steel	7.6-7.8	0.276-0.282	3-15	
Tin	7.3	0.265	15	0.15
Zinc	7.1	0.258	30	0.27

TABLE 6.—TYPICAL PROPERTIES OF SAND-CASTING ALLOYS

Alloy	Specific gravity	Weight, lb. per cu. in.	Electrical conductivity per cent of International Annealed Copper Standard	Thermal conductivity at 100°C., c.g.s. units*
43	2.66	0.096	37	0.34
43 annealed†	2.66	0.096	42	0.39
47	2.65	0.096	40	0.37
47 annealed†	2.65	0.096	32	0.39
108	2.75	0.099	31	0.29
108 annealed†	2.75	0.099	38	0.35
112	2.85	0.103	30	0.28
112 annealed†	2.85	0.103	38	0.35
122	2.85	0.103	34	0.32
122-T2	2.85	0.103	41	0.38
122-T61	2.85	0.103	33	0.31
142-T2	2.73	0.099	44	0.40
142-T61	2.73	0.099	37	0.35
195-T4	2.77	0.100	35	0.33
195-T62	2.77	0.100	37	0.34
214	2.63	0.095	35	0.32
214 annealed†	2.63	0.095	35	0.32
220-T4	2.56	0.092	31	0.20
A334	2.73	0.099	31	0.29
355-T4	2.68	0.097	35	0.33
355-T6	2.68	0.097	36	0.33
355-T51	2.68	0.097	43	0.40
A355-T51	2.71	0.098	32	0.31
356-T4	2.65	0.096	39	0.36
356-T6	2.65	0.096	39	0.36
356-T51	2.65	0.096	43	0.39
645	2.94	0.106	33	0.31
645 annealed†	2.94	0.106	35	0.33

\* C.g.s. units = calories per second per square centimeter per centimeter of thickness per degree centigrade.

† Although castings are not commonly annealed, similar effects on conductivities may result from the slower rate of cooling of thick sections as compared with thin ones and other variables in foundry practices. Comparison of the values for "as cast" and annealed specimens will show the extent to which variations may be expected, depending upon differences in thermal conditions in the production of different types of castings.

TABLE 7.—TYPICAL MECHANICAL PROPERTIES OF WROUGHT ALUMINUM ALLOYS

Alloy and temper	Tension				Hardness, Brinell, 500-kg. load, 10-mm. ball	Shear, shearing strength, lb. per sq. in.	Fatigue endurance limit, lb. per sq. in.
	Yield strength (set = 0.2 %), lb. per sq. in.	Ultimate strength, lb. per sq. in.	Elongation, per cent in 2 in.				
			Sheet specimen ( $1\frac{1}{16}$ in. thick)	Round specimen ( $1\frac{1}{2}$ in. diameter)			
2S-O	5,000	13,000	35	45	23	9,500	5,000
2S- $\frac{1}{4}$ H	13,000	15,000	12	25	28	10,000	6,000
2S- $\frac{1}{2}$ H	14,000	17,000	9	20	32	11,000	7,000
2S- $\frac{3}{4}$ H	17,000	20,000	6	17	38	12,000	8,500
2S-H	21,000	24,000	5	15	44	13,000	8,500
3S-O	6,000	16,000	30	40	28	11,000	7,000
3S- $\frac{1}{4}$ H	15,000	18,000	10	20	35	12,000	8,000
3S- $\frac{1}{2}$ H	18,000	21,000	8	16	40	14,000	9,000
3S- $\frac{3}{4}$ H	21,000	25,000	5	14	47	15,000	9,500
3S-H	25,000	29,000	4	10	55	16,000	10,000
11S-T3*	42,000	49,000	—	14	95	39,000	12,500
11S-T8	44,000	57,000	—	14	100	33,000	
17S-O	10,000	26,000	20	22	45	18,000	11,000
17S-T	40,000	62,000	20	22	100	36,000	15,000
Alclad 17S-T	33,000	56,000	18	—	—	32,000	
A17S-T	24,000	43,000	—	27	70	26,000	13,500
24S-O	10,000	26,000	20	22	42	18,000	12,000
24S-T	45,000	68,000	19	22	135	41,000	18,000
24S-RT	55,000	70,000	13	—	116	42,000	
Alclad 24S-T	41,000	62,000	18	—	—	40,000	
Alclad 24S-RT	50,000	66,000	11	—	—	41,000	
52S-O	14,000	29,000	25	30	45	18,000	17,000
52S- $\frac{1}{4}$ H	26,000	34,000	12	18	62	20,000	18,000
52S- $\frac{1}{2}$ H	29,000	37,000	10	14	67	21,000	19,000
52S- $\frac{3}{4}$ H	34,000	39,000	8	10	74	23,000	20,000
52S-H	36,000	41,000	7	8	85	24,000	20,500
53S-O	7,000	16,000	25	35	26	11,000	7,500
53S-W	20,000	33,000	22	30	65	20,000	10,000
53S-T	33,000	39,000	14	20	80	24,000	11,000
61S-O	8,000	18,000	22	—	30	12,500	8,000
61S-W	21,000	35,000	22	—	65	24,000	12,500
61S-T	39,000	45,000	12	—	95	30,000	12,500

\* For sizes up to  $1\frac{1}{2}$  in. For larger sizes, values are lower.

**Surface Protection, Coating, and Painting.**—Electrolytic corrosion may result from contact of magnesium alloys with other metals in solutions or chemicals that are ordinarily non-corrosive. Magnesium is electropositive to all other structural metals, but there is considerable variation in the degree of electrolytic attack caused by contact with various metals. The potential between magnesium and the non-copper-bearing aluminum alloys such as 2S, 3S, 4S, 51S, 52S, 53S, 56S, 214, and 220 is so small that contact with these alloys is usually harmless. Electrical insulation must be provided, however, in assemblies of magnesium and copper, copper-bearing aluminum alloys, brass, bronze, cast iron, steel, stainless steel, monel metal, chromium, nickel, tin, lead, solder, and similar alloys. Aside from aluminum, cadmium and zinc produce the least electrolytic attack.

TABLE 10.—PHYSICAL CONSTANTS OF MAGNESIUM ALLOYS

Alloy	Method of fabrication	Weight, lb. per cu. in.	Melting point, °F.	Temperature of incipient fusion, °F.	Thermal conductivity (100–300°C.), c.g.s. units	Electrical resistivity at 20°C. (68°F.), microhm per cm.	Electrical conductivity, expressed in per cent of annealed copper standard
AM3S	Extruded or rolled	0.064	1200	1200	0.30*	5.0	34.5
AM52S	Extruded	0.064	—	—	0.23*	10.0	17.2
AM53S	Rolled	0.064	1160	1050	0.23	10.0	17.2
AM57S } AMC57S }	Extruded or forged	0.065	1150	950	0.19*	14.0	12.5
AM58S	Extruded or forged	0.066	1110	895	0.18*	16.0*	10.8*
AM58S-T	Extruded	0.066	1110	895	0.18*	15.0*	11.5*
AM59S	Extruded	0.066	1100	855	0.17	18.0*	9.7*
AM59S-T	Extruded	0.066	1100	855	0.18	14.5*	11.9*
AM230-C	Cast	0.066	1100	816	0.17	15.0	11.5
AM240-C	Cast	0.066	1100	816	0.17	15.0	11.5
AM240-T4	Cast	0.066	1100	855	0.17	17.5	9.9
AM240-T61	Cast	0.066	1100	855	0.17	14.0	12.5
AM241-T4	Cast	0.065	1120	915	0.18	15.0	11.5
AM244-C	Cast	0.064	1160	1050	0.23	10.0	17.2
AM246-C	Cast	0.066	1075	816	0.16	16.5	10.5
AM246-T6	Cast	0.066	1075	816	0.16	14.0	12.5
AM265-C	Cast	0.066	1155	760	0.18*	11.5	15.0
AM265-T4	Cast	0.066	1155	760	0.18*	14.0	12.5
AM265-T6	Cast	0.066	1155	760	0.18*	12.5	13.8
AM403-C	Cast	0.064	1200	1200	0.30*	6.5	26.5

\* Approximate.

Notes: 1. For all the alloys, the mean coefficient of thermal expansion (65–750°F.) per degree Fahrenheit = 0.000016 (0.000029 per degree centigrade).

2. For all the alloys, the mean heat (20–350°C.) = 0.27 calories (approximately).

TABLE 11.—COMPOSITION OF WROUGHT MAGNESIUM ALLOYS

Alloy designation	Alloying constituents, per cent					Available conditions and their proper designations	Characteristic uses
	Al	Mn	Zn	Sr (max.)	Total impurities (max.)		
AM43S	—	1.2 min.	—	—	0.3	Rolled and heat-treated AM3S-O Cold-rolled after heat treatment AM3S-H Hot-rolled AM3S-R	Sheet and plate with good welding and forming characteristics Sheet or plate 0.1 in. thick and greater
AM52S	2.5-3.0	0.2 min.	1.3 max.	—	0.3	Extruded AM52S	Extruded rod of good elongation and impact resistance
AM53S	3.5-5.0	0.2 min.	0.3 max.	—	0.3	Rolled and annealed AM53S-O Hot-rolled AM53S-H	High-strength alloy for rolled sheet and plate
AM57S	5.8-7.2	0.15 min.	1.0 max.	—	0.3	Extruded AM57S Press-forged AM57S	Standard extrusion alloy. Screw machine rod forgings requiring good elongation and moderate strength
AMC57S	5.8-7.2	0.15 min.	1.5 max.	—	0.3	Extruded AMC57S Press-forged AMC57S	Same as AM57S. Extrusions with best corrosion resistance
AM58S	7.8-9.2	0.15 min.	0.8 max.	—	0.3	Extruded AM58S Extruded and aged AM58S-T Press-forged AM58S	Same as AM57S with greatly improved stability Extrusions requiring higher strength than AM57S Tubing with highest available properties Forgings with highest available properties
AM59S	9.5-10.5	0.10 min.	0.3 max.	—	0.3	Extruded AM59S	Extrusions requiring highest available hardness
AM63S	3.0-4.0	0.4 min.	—	4.0-6.0	0.3	Hammer-forged AM63S	Less expensive forgings of moderate strength
AM74S	2.5-3.5	0.2 min.	2.5-3.5	—	0.3	Forgings and extrusions AM74S Forgings and extrusions AM74S-T	For forgings, extrusions, and tubing requiring moderate strength For forgings, extrusions, and tubing of good properties in aged condition
AM88S	9.5-10.5	0.1 min.	2.0 max.	—	0.3	Extruded AM88S	Welding rod for AM240, AM241, AM246, and AM265 castings

TABLE 12.—CHEMICAL RESISTANCE OF MAGNESIUM AND ITS ALLOYS

Chemical or mixture	Concentration, per cent*	Recommended† for use‡
Acetic acid.....	Any	No
Acetylene.....	100	Yes
Alcohol, butyl.....	100	Yes
Alcohol, ethyl.....	100	Trial warranted
Alcohol, methyl.....	100	No
Alkali metal carbonates.....	Any	Yes
Alkali metal bicarbonates.....	Any	No
Ammonium fluoride.....	Any	Yes
Ammonium hydroxide.....	Specific gravity 0.93	Trial warranted
Ammonia gas or liquid.....	100	Yes
Ammonium salts (most).....	Any	No
Aniline.....	100	Trial warranted
Asphaltum.....	100	Yes
Beer.....	100	No
Benzene.....	100	Yes
Bichromates.....	Any	Yes
Borax solutions.....	1—3	Yes
Boric acid solutions.....	1—5	No
Bromides.....	Any	No
Butter.....	100	No
Calcium salts (most).....	3	No
Carbolic acid (phenol).....	100	Yes
Carbonic acid (carbonated water).....	Any	No
Carbon bisulphide.....	100	Yes
Carbon dioxide.....	100	Yes
Carbon monoxide.....	100	Yes
Carbon tetrachloride.....	100	Yes
Castor oil.....	100	Yes
Chlorides (all).....	Any	No
Chlorine.....	100	No
Chromates (most).....	Any	Yes
Chromic acid (pure).....	Any	Yes
Cyanides (most).....	Any	Yes
Diethylene glycol.....	100	Yes
Diethylene glycol solutions.....	Any	Trial warranted
Ethylene glycol.....	100	Yes
Ethylene glycol solutions.....	Any	Trial warranted
Fluorine.....	100	Yes
Fluosilicic acid.....	Any	No
Formaldehyde.....	50	Trial warranted
Fruit acids.....	Any	No
Gas (illuminating).....	100	Yes
Gasoline (lead free).....	100	Yes
Gasoline (leaded).....	100	Trial warranted
Grease (acid free).....	100	Yes
Heavy metal salts (most).....	Any	No
Hydraulic-brake fluids (most).....	100	Yes
Hydrochloric acid.....	Any	No
Hydrofluoric acid.....	10—50	Yes
Hydrofluoric acid.....	1—10	No
Hydrogen peroxide.....	3—30	No
Hydroxides (most).....	Any	Yes
Ink (iron).....	100	No
Ink (dye).....	100	Yes

TABLE 12.—CHEMICAL RESISTANCE OF MAGNESIUM AND ITS ALLOYS.—(Continued)

Chemical or mixture	Concentration, per cent*	Recommended for use†
Iodides.....	Any	No
Kerosene.....	100	Yes
Lanolin.....	100	Yes
Linseed oil.....	100	Yes
Mercury.....	100	No
Milk.....	100	No
Mineral acids (dilute).....	Any	No
Mineral acids (concentrated); fuming $\text{HNO}_3$ and fuming $\text{H}_2\text{SO}_4$ or mixtures of same have no action on magnesium, but use is not recommended.....		
Nitrates (most).....	Any	No
Oil, animal (acid free; chloride free).....	100	Yes
Oil, mineral (chloride free).....	100	Yes
Oil, vegetable (chloride free).....	100	Yes
Organic acids.....	Any	No
Oxygen.....	100	Yes
Permanganates (most).....	Any	Yes
Phenol (carbolic acid).....	100	Yes
Phosphates (most).....	Any	Yes
Phosphoric acid ( $\text{H}_3\text{PO}_4$ ).....	Any	Trial warranted
Potassium fluoride.....	Any	Yes
Potassium hydroxide.....	Any	Yes
Potassium salts (most).....	3	No
Rubber cement.....	100	Yes
Salt (sodium chloride).....	Any	No
Sea water.....	100	No
Sodium fluoride.....	Any	Yes
Sodium salts (most).....	3	No
Sodium silicate (water glass).....	3—50	Yes
Steam.....	100	No
Sulphates.....	Any	No
Sulphur.....	100	Yes
Tar.....	100	Yes
Tung oil.....	100	Yes
Turpentine.....	100	Yes
Vinegar.....	Any	No
Water (distilled < 100°F).....	100	Yes
Water (distilled > 100°F).....	100	No
Water (tap).....	100	No

\* Concentrations other than 100 per cent refer to water solutions.

† Refers to performance at room temperature only unless other temperatures are specified.  
“Trial warranted” indicates that use may be satisfactory and that a trial or operating conditions is warranted.

Under ordinary conditions, the rate of corrosion of magnesium is lower than that of mild steel. Test specimens of one of the magnesium alloys when exposed to ordinary atmospheric conditions suffer little or no loss in mechanical properties, even after 7 years. Mild steel samples exposed concurrently show considerable loss in section and severe scaling.

Upon exposure to inland atmospheres, magnesium alloys gradually darken and acquire a thin film of magnesium hydroxide and magnesium

carbonate. This film is not impervious, but it is adherent, and, once formed, it retards subsequent attack. If the temperature and humidity are not too high, magnesium alloys do not corrode to any serious extent, even when exposed to sea air and spray. Bare (unpainted) magnesium-alloy test panels exposed at Point Judith, R. I., within 100 ft. of the Atlantic Ocean, showed only slight attack after 2 years and little additional change after 2 more.

However, as the humidity and average temperature increase, the rate of corrosion is accelerated, and in tropical or semitropical climates, magnesium alloys must always be protected with paint. Under conditions of high humidity, the salt present in the air along the seaboard precipitates out with the water when the dew point is reached and greatly accelerates the rate of corrosion. Thus, although the danger of corrosion is not great along the North Atlantic coast, it may become serious in more southerly coastal regions. Unless it is possible to predict where the finished product containing magnesium-alloy parts is to be used, it is advisable to protect the magnesium parts with an approved paint system to withstand the most severe conditions of exposure. In other cases, from the standpoint of appearance, it is known that they will be used indoors or in non-corrosive atmospheres.

Buffed or polished magnesium surfaces tarnish in ordinary atmospheres. Wax will preserve such a surface for a while, but the most satisfactory method of protecting buffed surfaces is by coating with clear resin lacquer such as Hercose C, but even lacquered buffed surfaces will not endure exposure to weather. In order to obtain a paint job that will be satisfactory under any of the varied conditions of service, the following sequence of operations must be strictly adhered to:

1. Surface cleaning.
2. Chemical treatment of the surface.
3. Priming.
4. Painting.

**Surface Cleaning.**—Magnesium-alloy castings, forgings, sheet, and extruded sections produced by the American Magnesium Corp. are dichromated before shipment, and if they are to be used as received, the products are ready for painting after being wiped with naphtha or gasoline. In most cases however, machining or forming operations are made, and the finished articles require cleaning to remove dirt, oil, or grease before paint can be properly applied.

Satisfactory cleaning may be accomplished with naphtha, gasoline, trichloroethylene, carbon tetrachloride, or hot alkaline cleaners. Commercial cleaning solutions or compounds containing mineral or organic acids are to be avoided. The mild alkaline cleaning solutions developed for aluminum may be used, but since magnesium alloys are not attacked by even highly alkaline solutions, it is possible to effect more rapid and



more efficient cleaning by the use of such solutions. A solution made according to the following formula will be found to clean magnesium-alloy parts in a satisfactory manner:

Sodium carbonate.....	3 oz.
Sodium hydroxide.....	2 oz.
Soap.....	1 oz.
Water.....	To make 1 gal.

This solution should be used boiling hot, and after treatment the parts should be thoroughly washed in cold running water. Drying of the parts will be facilitated if they are given a final rinse in hot water. Cleaning solutions containing soap, like the preceding, should not be used unless the parts will interfere with the adhesion of the paint film to the metal. When cleaning parts, properly dichromated, the use of gasoline, naphtha, carbon tetrachloride, trichloroethylene, or soap-free alkaline solutions is recommended.

**Chemical Treatment of the Surface—Coatings.** *A.M.C. Treatment A.*<sup>1</sup>—The chemical treatment applied to the surface of all magnesium-alloy products produced by the American Magnesium Corp. was formerly known as the “dichromate coating” or “chrome pickle” but is now termed “A.M.C. treatment A.” Although this coating will resist tarnish for long periods of time when not exposed to weathering and although it passivates the surface so that the initial rate of attack by salt solutions is greatly reduced, it is most valuable when used as a base for paint. Neither the dichromate coating nor the other coatings subsequently described have the protective characteristics of the oxide coatings applied to aluminum alloys.

The excellence of the A.M.C. treatment A as a paint base is due to the passivation of the metal surface coupled with an etching effect that produces a surface to which paint can adhere.

The A.M.C. treatment A is applied simply by dipping the article to be coated in a solution made according to the following formula:

Sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ).....	1.5 lb.
Concentrated nitric acid (specific gravity = 1.42).....	1.5 pt.
Water.....	To make 1 gal.

The solution may be used at room temperature, or it may be heated to as high as 150°F. if it is desired to increase the rate of reaction. It is generally more satisfactory to use the solution at room temperature, since this reduces concentration changes through evaporation and avoids the cost of heating.

<sup>1</sup> Conforms to Navy Aeronautical Specification M303a and to U. S. Army Specification 98-20010-A.

## MAGNESIUM AND ITS ALLOYS

The duration of the dip varies from 30 sec. to 2 min., depending upon the age of the solution. The proper length of time to allow the article to remain in the dichromating solution may be readily determined by trial. The article to be coated should be immersed in the solution for the requiring length of time and then allowed to drain for 5 to 20 sec. and rinsed in cold running water, followed by an immersion in water at about 180°F.

The purpose of the hot-water rinse is to heat the article thoroughly to facilitate drying. If the time of dip in the dichromating solution has been long enough, the article will have a yellow or yellow-red iridescent color. If the color is pale and contains areas that are apparently uncoated, the duration of the dip should be increased. The proper time of dip is the shortest time that will produce a coating of the proper color. All the alloys of magnesium do not take the dichromate coating in the same way, and there is considerable difference in the appearance of the various alloys after dichromating, but a little experience with any particular alloy will soon teach the operator how to work the process in order to obtain the proper coating.

After a tankful of the dichromating solution has treated a certain number of articles, it becomes weak, and its rate of reaction with the magnesium is reduced to such an extent that a 2-min. immersion will not produce the proper color and etch. When this point is reached, the solution should be revived by adding the proper amount of nitric acid. The solution may be revived in this manner about five times, after which it is advisable to make up a fresh solution.

The composition of the solution may be controlled by analysis or by specific gravity, and where large quantities of metal are to be handled, these methods of control will be found to be more satisfactory than to rely on the color of the coating produced in order to tell when the solution should be revived. Complete details of these methods of control will be furnished on request. The container of the dichromating solution should be of commercially pure aluminum (2S), glass, or earthenware. Articles too large to be immersed in the container available may be brushed or swabbed with newly made dichromating solution.

The A.M.C. treatment described above removes a certain amount of metal from the surface of the article treated. The amount removed depends upon the time of immersion, the acid concentration of the solution, and the temperature of the solution. Under certain conditions, as much as 0.001 in. of metal may be removed from the surface of an article immersed for 2 min. in a fresh dichromating solution. A change in dimensions of this magnitude cannot be tolerated on accurately machined parts. Magnesium parts containing machined surfaces that are to be painted or on which it is desired to prevent tarnish may be coated by any of the following treatments without danger of dimensional change:

- A.M.C. treatment B.
- A.M.C. treatment C.
- A.M.C. treatment D.
- A.M.C. treatment E.
- A.M.C. treatment F.
- A.M.C. treatment G (Army 98-20010-A).
- A.M.C. treatment H (Navy M382).
- Naval aircraft-factory anodic treatment PT-13.

*A.M.C. Treatment B.*—A.M.C. treatment B is applied to thoroughly degreased and cleaned magnesium-alloy parts in the following manner. The surface that has previously been given the dichromate coating described under heading B will successfully take the A.M.C. treatment B coating provided that the surface is absolutely clean.

1. Immerse the parts to be treated for 5 min. in a boiling solution containing 2 per cent by weight of sodium hydroxide (NaOH).
2. Rinse thoroughly in hot running water.
3. Immerse for  $\frac{1}{2}$  hr. in a boiling solution of:

Alkaline dichromate solution	Metric unit	English unit
Potassium dichromate ( $K_2Cr_2O_7$ )...	15 g.	2 oz.
Ammonium sulphate ( $(NH_4)_2SO_4$ )...	30 g.	4 oz.
Ammonium dichromate ( $(NH_4)_2O_7$ )...	15 g.	2 oz.
Distilled water to make.....	1 l.	1 gal.

4. Wash thoroughly in hot running water.
5. Dry in an oven at 140°F.; or dip in clean boiling water, and dry in air.

The container for the alkaline dichromate solution may be of aluminum or steel.

The correct acidity of the solution is very important and can be checked only by using a hydrogen-ion indicator outfit. The pH value should be kept between 6.0 and 6.4, and the range of pH values must be maintained by a periodic check of the solution, with the use of the hydrogen-ion comparator with bromocresol purple indicator for pH5.2 to 6.8.

*A.M.C. Treatment C.*—A.M.C. treatment C is a special coating usually applied only to AMC57S and AM58S. This coating has a low dielectric strength and is especially suitable for use on electrical fittings and conduit of AMC57S. Tests have shown that AMC57S conduit fittings coated by this treatment require no further protection and that AMC57S with this coating is more resistant to salt-water corrosion than bare aluminum alloy 17S-T.

This coating may be applied by two different procedures, the first being suitable for small-scale or occasional use, the second being recommended for quantity production. In both procedures, the coating bath is the same and is made up of:

AMC-C coating solution	Metric unit	English unit
Magnesium sulphate ( $\text{Mg}_2\text{SO}_4 \cdot 7\text{H}_2\text{O}$ ).....	60 g.	8 oz.
Potassium dichromates ( $\text{K}_2\text{Cr}_2\text{O}_7$ ).....	40 g.	5.3 oz.
Water to make.....	1 l.	1 gal.

This bath, hot or cold, may be held in glass, aluminum, iron, or earthenware tanks.

Thorough cleaning of the pieces prior to immersion in the solution is essential to the successful application of this coating. The cleaned articles should show an unknown film of water when rinsed after cleaning.

*Procedure A* (for small-scale or occasional use) is as follows:

1. Clean in carbon tetrachloride, high-test gasoline, or other good grease solvent. Commercial alkaline cleaners may also be used if available.

2. Rinse well in running water to remove all traces of cleaner.

3. Dip in the chrome sulphate bath given above for 30 to 60 min. at room temperature. The magnesium articles in the bath must be insulated from all dissimilar metals and not be allowed to touch the tank if it is of metal.

4. Rinse in cold running water and then in hot water to facilitate drying. Control: Use the bath until satisfactory coatings (as indicated by color) are no longer obtained, and then make up a fresh solution.

*Procedure B* (for production use) is as follows:

1. Clean for 2 min. in water solution containing 4 oz. per gallon of Oakite No. 20 Cleaner maintained at 160 to 180°F. or for 2 min. in a water solution containing 4 oz. per gallon of Zophite Cleaner No. 288 maintained at 180°F. Other commercial cleaners or grease solvents may be used if trial shows that they clean thoroughly and do not cause the work to become discolored in the chrome-sulphate bath.

2. Rinse well to remove all traces of cleaner, and eliminate carry-over into the chrome-sulphate bath.

3. Dip in the chrome-sulphate bath given above for 10 to 20 min. at 150 to 160°F. The magnesium articles must be insulated from dissimilar metals. An earthenware dipping basket is recommended.

4. Rinse in cold running water and then in hot water to facilitate drying.

Control: Maintain pH at 3.0 to 4.0, since bath becomes slow-acting if pH rises above 4.0. Maintain pH by small additions of  $\text{H}_2\text{SO}_4$  made after each load or every other load. Replace water lost by evaporation. Maintain proper  $\text{K}_2\text{Cr}_2\text{O}_7$  content by analysis. Additions of  $\text{MgSO}_4$  do not appear to be necessary.

*A.M.C. Treatment D.*—1. Boil the article to be coated for 15 to 20 min. in a solution of:

AMC-D coating solution	Metric unit	English unit
Sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ).....	120 g.	1 lb.
Monobasic sodium phosphate ( $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ ).....	120 g.	1 lb.
Water to make.....	1 l.	1 gal.

2. Rinse in cold running water.

3. Wash in hot water to facilitate drying.

Any powdery deposit left on the surface should be brushed off. An aluminum tank is a satisfactory container for this solution.

*A.M.C. Treatment E.*—This coating is particularly useful for imparting a decorative finish to magnesium-alloy die castings. Die castings that are to be painted may also be treated by this process, but this is not usually economically desirable, because A.M.C. treatment A can be applied to die castings at less cost and provides a satisfactory base for paint. Die castings processed by treatment A do not have a very attractive appearance, and so A.M.C. treatment E is recommended where appearance is important. It is not recommended for prolonged outdoor exposure or severe service without additional paint protection.

The color of the coating varies from dark brown to black, and more uniform coatings are obtained if the cast surface is removed by machining, buffing, filing, or sanding.

A tank suitable for the chrome-alum coating should be of welded construction from aluminum sheet. The sheet recommended is 2S- $\frac{1}{2}$ H or 3S- $\frac{1}{2}$ H. A cover should be provided for the tank to prevent excessive waste of the solution while boiling. Baskets or hooks used to hold the material while in the solution should also be fabricated from aluminum. A hood should be provided to carry off the irritating vapors produced by the boiling solution when the castings are being treated. These vapors attack the membranes of the nose and throat. If it is impossible to use a hood, the operator should wear a respirator with the pads moistened with water. Heat must be provided to keep the solution at a steady boil while the coating is being applied.

The stock solution for the tank has the following composition:

AMC-E coating solution	Metric unit	English unit
Potassium chrome alum ( $K_2Cr_2(SO_4)_4 \cdot 24H_2O$ ) . . .	30 g.	4 oz.
Sodium dichromate ( $Na_2Cr_2O_7 \cdot 2H_2O$ ) . . . . .	100 g.	13.3 oz.
Water to make . . . . .	1 l.	1 gal.

Technical grades of chemicals are used. Time of treatment is 2 to 15 min., according to freshness of solution.

The amount of solution needed is calculated from the surface area to be coated and the number of pieces to be coated at one time. Each square inch of surface area requires at least 10 cc. of solution. Twice this volume is recommended as a factor of safety. This solution has to be revived by the addition of sulphuric acid at definite intervals. Either of the following two methods of controlling the acidity of the coating bath are suitable. Method 1 is preferred because it produces blacker coatings and the variation in color between batches is less than in method 2.

Method 1.—With this method, uniform black coatings are obtained without a decided difference in color between any two separate batches. The surface area of the entire batch of castings run at one time must never exceed the capacity of the solution, *viz.*, 10 cc. of solution per square inch of casting. After each batch 1 cc. of 1:3  $H_2SO_4$  is added for each 25 sq. in. of surface area. This method keeps the acid entirely depleted, at which time additional amounts of acid have no effect on the solution.

Assume that the tank contains 20 l. of solution and that each casting has a surface area of 500 sq. in. and requires at least 5 l. of solution; an acid addition is made. (The  $H_2SO_4$  is diluted to 1:3 to prevent any violent reaction as it is added to the boiling solution.) Since each batch has 500 sq. in. surface area and 1 cc. of 1:3  $H_2SO_4$  is added for each 25 sq. in. of area, 20 cc. is added after each batch is coated.

With this method, brown coatings should not appear until the bath gets exhausted. At this point, regardless of the amount of acid added, black coatings cannot be obtained, and the bath should be discarded.

Method 2.—With this method, batch after batch of castings may be coated until brown instead of black coatings are produced. At this point, 2.5 cc. of concentrated  $H_2SO_4$  per liter ( $\frac{1}{3}$  fluid oz. per gallon) is added to the solution. This should be added as 1:3  $H_2SO_4$  to prevent violent reaction as the acid is poured into the boiling tank. This acid addition may be repeated about four times; when the point is reached where additional acid has no effect on the color, the solution must be discarded.

If facilities are available for hydrogen-ion determinations, the solution may be controlled by additions of acid to maintain the pH value at 2.5 to 3.5. The pH of an exhausted solution is 5.5.

The surface preparation of the casting to be coated is extremely important, if a uniform black coating is desired. As a matter of fact, deep black coatings can be obtained only on machined, buffed, ground, scratch-brushed, or sanded surfaces. The "as cast" surfaces of AM263, AM230, AM265, or AM240 die castings do not coat uniformly and have a tendency to show gray areas. The castings must be free from grease and oil.

Chips from reaming or drilling operations that adhere to the casting also cause trouble in the form of spots in the coating, and hence all chips and metal dust must be removed from the casting before coating.

The following notes will be of interest to plant personnel applying this treatment:

1. The solution must be boiling (212°F.) to obtain uniform black coatings.

2. Surfaces must be free from grease or oil.

3. Scratch brushing or polishing produces a coating that does not mar easily.

4. Sand- or dust-blasted surfaces taken an even black coating that marks more easily than other types of surface.

5. After acid additions, the solution must be stirred.

6. Keep the solution up to the correct level by adding water each day or whenever necessary.

7. Wash the castings in running cold water immediately after removal from the coating bath. Follow with a hot-water rinse to facilitate drying.

8. An air blast will help to dry the pieces more uniformly.

9. Holes or pockets should be washed out thoroughly to prevent discoloration.

10. If the castings have a brown, powdery coat after drying, brush off with a bristle brush, either wet or dry.

11. The time of immersion may vary from 2 to 15 min.

12. Do not allow castings to rest on each other, because areas of contact are not coated. Castings resting on bottom of baskets made of heavy aluminum wire will coat satisfactorily.

13. A.M.C. treatment E works equally well on AM230, AM263, AM265, or AM240. In fact, the alloy composition probably has little influence on the character of the coating obtained.

*A.M.C. Treatment F.*—This treatment can be applied to all Mazlo magnesium alloys, including AM3S, to which some coatings will not adhere. It is recommended only as a base for paint, the function for

which it was developed and for which it is admirably suited. Castings containing inserts of brass, bronze, steel, or aluminum may be treated by this process without damage.

### Instructions for Applying.

#### 1. *Precleaning.*

a. Castings.—Rough castings should be dipped for 1 min. in 1.5 per cent  $\text{H}_2\text{SO}_4$ , washed, and then boiled in 5 per cent  $\text{NaOH}$  for 2 to 5 min. In treating machined castings, the acid dip is dispensed with. Machined castings should be degreased and then immersed for 2 to 5 min. in boiling 5 per cent  $\text{NaOH}$ .

b. Forgings, Sheet, Extrusions.—Degrease and boil for 2 to 5 min. in 5 per cent  $\text{NaOH}$ .

#### 2. *Coating.*

a. Immerse the article in the following solution for 30 min. at 98 to 100°C. Use aluminum, glass, or earthenware containers.

	Metric unit	English unit
$3\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$ .....	50 g.	6.6 oz.
$\text{K}_2\text{Cr}_2\text{O}_7$ .....	100 g.	13.3 oz.
Water.....	To make 1 l.	To make 1 gal.

b. Rinse in cold and then hot water, and dry.

3. *Control.*—The hydrogen-ion concentration of the coating solution should be maintained at pH values between 4.4 and 4.8. Painting immediately after the coating is dry is recommended.

*A.M.C. Treatment G.*—This treatment is recommended for application to magnesium castings and most wrought alloys. It is not suitable for AM3S. For the most complete protection against corrosive conditions, the articles coated should be painted as recommended later. Inserts, studs, bearings, etc., of brass, bronze, and steel are not attacked by nor do they affect the treatment. Any aluminum present, however, must be protected as it is rapidly attacked during the hydrofluoric acid dip. A prior coating according to A.M.C. treatment A does not interfere with the application of A.M.C. treatment G. This treatment causes no dimensional changes. The color of the coating obtained varies from brown to black. The coating is soft and is easily scratched. Paint adheres well to it and should always be applied as soon after coating as possible. This treatment corresponds to that covered by U. S. Army specification 98-20010A.



### Instructions for Applying.

*Cleaning.*—Machined castings or clean fabricated articles should be thoroughly degreased in naphtha, carbon tetrachloride, trichloroethylene, or other suitable solvent. Commercial alkaline cleaners may also be used. Rough castings may be cleaned by dipping in nitric or sulphuric acid or in an aqueous solution containing 8 parts concentrated  $\text{HNO}_3$  and 2 parts concentrated  $\text{H}_2\text{SO}_4$  by volume, followed by thorough rinsing. The acid dip should never be used on machined castings.

### Coating.

1. Immerse parts to be coated for 5 min. in a bath containing 38 to 52 per cent hydrofluoric acid (HF, technical grade), 1 part by volume, and water, 2 parts by volume.

2. Wash in cold running water.

3. Boil for at least 45 min. in an aqueous solution containing  $\frac{3}{4}$  lb. per gallon of sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ). This is equivalent to 10 per cent  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$  by weight (100 g. per liter).

4. Rinse thoroughly in cold running water and in hot water to facilitate drying.

*Control of Solution.*—No control of either solution used appears to be necessary. The HF must be replaced from time to time because of mechanical loss. Large-scale operations may reveal the necessity for some control of the  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$  solution, which should be replaced frequently.

*Tank Materials.*—The acid pickling solutions may be held in ceramic, aluminum, rubber-lined steel, or other suitable tanks. Lead or lead-lined wood tanks are suitable for the hydrofluoric acid solution. The sodium dichromate solution can be held in iron, aluminum, magnesium, or wood, and some means of maintaining boiling temperature must be provided.

*A.M.C. Treatment H. (General).*—This treatment may be used on magnesium alloys, especially sand castings after machining and before painting.

Protective paint systems should always be applied over this coating.

Castings containing bearings, studs, or non-magnesium inserts of any nature may sometimes require this treatment, as in the case of refinishing work. Brass, bronze, and steel are unaffected by the treatment. Aluminum, however, is rapidly attacked during the hydrofluoric acid dip.

Magnesium sand castings are furnished to the user with a chemical treatment known as the A.M.C. treatment A. This treatment provides protection during shipment, storage, and machining. Treatment A coating remaining on the unmachined areas will not impair the H treatment

and consequently does not need to be removed. This treatment corresponds to that covered by Navy aeronautical specification M382 and is acceptable as alternate for anodic treatment PT-13 (effective at the date of writing).

### Instructions for Applying.

*Cleaning.*—Machined castings should be thoroughly cleaned from all trace of grease and oil by washing in carbon tetrachloride, naphtha, or other suitable solvent. Commercial alkaline cleaners may also be used.

NOTE: If, before machining the magnesium castings, it is observed that they contain dirt not removable by organic solvent or alkaline cleaner or if they exhibit visible surface oxidation, the castings must be treated as follows.

Dip the casting 10 sec. in a solution at room temperature containing by volume 8 parts of concentrated nitric acid, 2 parts of concentrated sulphuric acid, and 90 parts of water. Wash thoroughly in running water. Follow by a dip in hot water to facilitate drying. The casting is now ready for machining operations, immediately after which the casting must be cleaned and treated according to the recommendations given. The nitric-sulphuric acid pickle is seldom required on Mazlo magnesium castings as received from the foundry. Castings stored for any length of time under unfavorable conditions may require it. When the nitric-sulphuric acid pickle is indicated, *it must be applied before any machining*, since the amount of metal removed is likely to exceed machined dimensional tolerances. It is quite safe, however, to pickle the rough, un-machined castings.

### Coating.

1. Immerse castings for 5 min. in a water solution containing 15 to 20 per cent by weight of hydrofluoric acid (HF) at room temperature. A satisfactory bath can be prepared by diluting one volume of technical grade 48 to 52 per cent HF with two volumes of water.

2. Wash thoroughly in cold running water.

3. Boil castings for at least 45 min. in a water solution containing the following ingredients (technical grades are satisfactory):

AMC-H coating solution	Metric unit	English unit
Ammonium sulphate $(\text{NH}_4)_2\text{SO}_4$ 3.0%.....	30 g.	4 oz.
Sodium dichromate $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ 3.0%.....	30 g.	4 oz.
Ammonia (specific gravity = 0.880) 0.5%.....	5 cc.	$2\frac{1}{3}$ oz.
Water to make.....	1 l.	1 gal.

The original solution level should be maintained by additions of water to replace that lost by evaporation.

4. Wash thoroughly in cold running water.

5. Boil castings for at least 5 min. in a water solution containing 1 per cent by weight of arsenous oxide ( $\text{As}_2\text{O}_3$ ). This solution can be readily prepared by adding technical arsenous oxide to water in the ratio of 1 oz. per gallon. The original solution level should be maintained by additions of water to replace that lost by evaporation.

6. Rinse castings thoroughly in cold running water; follow by a dip in hot water to facilitate drying.

*Tank Materials.*—The nitric-sulphuric acid pickling bath may be contained in ceramic, rubber-lined, aluminum, or other suitable tanks. Lead tanks may be used for containing the hydrofluoric acid bath. Iron tanks lined with acid-resistant rubber compounds have also been used satisfactorily. The boiling sulphate-dichromate-ammonia solution can be used in iron, aluminum, wood, or almost any of the commonly used tank materials. A loose-fitting lid should be used to minimize evaporation. The boiling arsenous oxide solution can be used in iron, aluminum, magnesium, wood, or almost any of the commonly used tank materials. A loose-fitting lid should be used to minimize evaporation. Hood or other exhausting equipment should be provided for the hydrofluoric acid, the ammonium sulphate-dichromate solution, and the arsenous oxide solution.

*Control of Solutions.*—The hydrofluoric acid and arsenous oxide baths last indefinitely. One tankful of the sulphate-dichromate-ammonia solution may be used to treat about 10 full loads of material before exhaustion takes place. After this, the solution should be rejected and renewed.

Properly applied coatings will vary from dark gray to black. Time of treatment, condition of bath, and alloy composition will influence color of coating. This treatment effects no changes on dimensions or luster of magnesium surfaces. Painting should be done as soon as possible after application. Inhibitive type primers such as Navy P-27 and Army 14080 are recommended. Water-resistant enamels or I-12a 3-158 lacquers should be used for top coats.

*A.M.C. Treatment J.*—This treatment imparts a decorative finish to all Mazlo magnesium alloys, including AM3S. It is especially valuable in treating assemblies of two or more different alloys. It has been found that some coatings will not adhere to the alloy in the assembly possessing the higher solution potential. The use of A.M.C. treatment J has, in several instances, overcome this difficulty. This treatment followed by waxing, produces a decorative bronze to dark brown finish that is satisfactory for many purposes but is not, of course, recommended for severe

corrosive conditions. It may also be used as a base for paint, but it is not so effective in this respect as A.M.C. treatments A, F, G, or H.

*Precleaning.* Castings.—Rough castings should be dipped in 1.5 per cent  $\text{H}_2\text{SO}_4$  for 1 min., washed, and then boiled for 2 to 5 min. in 5 per cent  $\text{NaOH}$ . In treating machined castings, the acid dip is dispensed with. Machined castings should be degreased and then boiled for 2 to 5 min. in 5 per cent  $\text{NaOH}$ .

Forgings, Sheet, Extrusions.—Degrease, and boil for 2 to 5 min. in 5 per cent  $\text{NaOH}$ .

### *Coating.*

1. Immerse articles for 30 min. in solution at 98 to 100°C., made up in the following manner:

AMC-J coating solution	Metric unit	English unit
$\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ 27 to 28% free $\text{Al}_2\text{O}_3$ .....	500 g.	4 lb. 3 oz.
$\text{K}_2\text{Cr}_2\text{O}_7$ .....	50 g.	6.6 oz.
MPD189*.....	2 g.	0.26 oz.
Water to make.....	1 l.	1 gal.

\* Wetting agent made by E. I. Du Pont de Nemours & Co.

2. Rinse in cold and hot water, and dry. Use aluminum, glass, or earthenware container for the solution.

*Control.*—The hydrogen-ion concentration of the solution should be maintained at pH values between 2.0 and 2.9. Painting immediately after the coating is dry is recommended.

*Anodic Treatment.*—Information on the N.A.F. anodic coating may be obtained from the "Naval Aircraft Factory Process Specification PT-13 for Protective Treatment of Magnesium Base Alloys by an Anodic Oxidation Process." Copies may be obtained from the Manager, Naval Aircraft Factory, Navy Yard, Philadelphia, Pa.

In the table on page 66, the Mazlo magnesium alloys are arranged according to commodity, and applicable coating treatments are indicated.

*Painting.*—So far as the problem of protecting magnesium alloys with paint is concerned, the service conditions to be met fall into three general classes:

1. Interior, such as in the home, office, or factory not employing corrosive chemicals.

2. Exterior, such as inland North American atmospheres.

3. Seaboard atmospheres containing sea salts and/or spray or tropical areas of high humidity.

The painting systems that have been developed to meet the three conditions of service mentioned above may be divided, for the purpose of discussion, into two general types according to the kind of primer used. Primers possessing maximum adhesive qualities are recommended for the

Commodity	Alloys	Condition	Suitable coatings*	Recommended coating†
Sand or permanent mold castings	AM240, AM241, AM244, AM246, AM260, AM265 AM403 AM240, AM241, AM244, AM246, AM260, AM265 AM403	Rough-cast Rough-cast	A, B, F, G, H, Pt-13 A, F, Pt-13	A
		Machined Machined	B, F, G, H, Pt-13 F, Pt-13	G F or PT-13
Die castings	AM230, AM240, AM241, AM263	Die-cast	A, F, G, H, E	E or A
Extrusions or products made from extrusions	AM52S, AM57S, AMC57S, AM58S, AM59S, AM65S, AM74S AM3S AM53S, AM57S, AMC57S, AM58S, AM59S, AM65S, AM74S AM3S AMC57S electrical fittings AM3S electrical fittings	Extruded Extruded	A, B, F, G, H, J, Pt-13 A, F, Pt-13, J	A A
		Machined	B, D, F, G, H, J, Pt-13	G
		Machined Machined Machined	F, Pt-13, J C, A Modified A ‡	F or Pt-13 C Modified A ‡
Sheet or products from sheet	AM52S, AM53S, AMC57S AM3S, AM37S	Rolled or formed Rolled or formed	A, B, F, G, H, J, Pt-13 A, F, J, Pt-13	A A
Forgings	AM57S, AMC57S, AM65S, AM74S AM3S AM57S, AMC57S, AM58S, AM65S, AM74S AM3S	Rough Forged Forged	A, B, F, G, H, J, Pt-13 A, F, J, Pt-13	A A
		Machined Machined	B, D, F, G, H, J, Pt-13 F, J, Pt-13	G F or Pt-13
Miscellaneous	AMC57S electrical fittings AM3S electrical fittings	Machined Machined	C, A Modified A ‡	C Modified A ‡

\* Coatings that will adhere to alloys specified and that could be used if desired.

† Most desirable coating, considering protective value, paint adherence, stability of dimensions, ease of application, and cost.

‡ Modified A is short dip of 10 sec. in solution of A.M.C. treatment A to keep dimensional change to minimum.

NOTES: A.M.C. treatment A is covered by Navy aeronautical specification M303a and U. S. Army 98-20010A.

A.M.C. treatment G is covered by U. S. Army specification 98-20010A.

A.M.C. treatment H is covered by Navy aeronautical specification M382.

conditions of service marked (1) and (2); inhibitive primers whose pigments are largely or entirely zinc chromate are recommended for the severe service conditions marked (3). In cases in which it is difficult to predict the service conditions under which a piece of equipment, such as

an aircraft motor, will be used, it is usually best to employ the inhibitive Zinc Chromate Primers.

When appearance is of importance, surfacers or fillers may be used over the primer prior to applying the finish coats. For conditions of severe exposure, however, an additional finish coat has more protective value than a coat of surfacer.

The type of finish paint that should be used depends upon the service conditions to be encountered. For indoor exposure, practically any kind of paint applied over an adherent primer will give satisfactory results, although quick-drying, brittle lacquers should be used with caution, since magnesium alloys have a high coefficient of expansion that causes inelastic paints to crack and flake off.

For exterior work in atmospheres free from chlorides, oil-base synthetic resin enamels of the glycerol phthalate or of the phenolic type have given the best results. High-grade spar varnishes pigmented with Albron (Aluminum Co. of America) or the corresponding enamels are also quite satisfactory for this type of service.

For finish coats that must withstand the most severe service conditions (Class 3), the oil-base phenolic resin (Bakelite) enamels or an oil-base phenolic resin varnish pigmented with Albron paste is recommended. This type of finish coat may be baked at temperatures up to 250°F., and for best results both the primer and finish coats should be baked for 1 hr. at 225 to 250°F. Baking produces a notable improvement in adhesion and resistance to penetration by moisture.

The painting system recommended to meet severe (Class 3) service conditions is as follows:

1. One coat of Zinc Chromate Primer meeting Navy specification P-27 or Army specification 14080. Bake 30 min. to 1 hr. at 225 to 250°F.
2. Three coats of enamel meeting Navy specification M67 or three coats of synthetic resin varnish meeting Navy specification V-10 pigmented with 2 lb. of Albron paste per gallon. Bake each coat 1 hr. at 225 to 250°F.

Occasionally there are objections to the expense of applying three finish coats. Although it is true that two finish coats will, in most instances, provide satisfactory protection, the additional protection provided by the third coat is well worth the expense, especially on parts to be used on naval aircraft.

Many well-known manufacturers of paint are now making primers and finishes suitable for use on magnesium. Inasmuch as it is impossible to test all the great number of paints on the market, it is not believed advisable to list primers and finishes that have been tested and found satisfactory. To do this might discriminate against highly satisfactory products that have not been tested. However, the suitable paints fall

into rather definite classes, and with the following table as a guide, reputable manufacturers will be able to advise which of their products meet the specifications or general requirements as the case may be.

Castings forming parts of machines or motors are often painted before assembly, and during the assembly process paint may be chipped off; or it may be discovered that some unpainted areas are exposed to corrosion. In such cases, it is recommended that the assembled machine or motor be touched up with a coat of primer and one or more coats of finish paint. Inspection and maintenance of the protective paint film in the field are very important, and the ultimate user should be instructed in the proper way to care for the magnesium-alloy parts of his equipment.

The question occasionally arises as to what effect the heating incidental to the baking of paint has upon the mechanical properties of magnesium alloys. If the baking times at temperatures recommended in the foregoing table are adhered to, the heating and cooling involved will have no important effect on the properties of any of the commercial magnesium alloys now in use. However, there may be times when the user desires to employ enamel that is baked in the range 300 to 400°F.

The effect of baking temperatures in this range on the properties of magnesium alloys depends on their previous history. Wrought alloys, with the exception of AM59S, would be unaffected by any reasonable baking periods at 300 to 400°F. Cast alloys in the "as sand cast" (C) or in the "fully aged" (T6) conditions would be unaffected by heating for 1 or 2 hr. at these temperatures, but castings in the heat-treated (T4) condition tend to age and harden with consequent increase in yield strength and reduction in elongation.

The same would be true of the wrought AM59S alloy. This change in properties takes place slowly, and the extent of the change depends upon the length of time and temperature. The changes brought about by 2 hr. at 300°F. or 1 hr. at 400°F. are comparatively unimportant and will not affect the service life of the magnesium part. However, heating AM240-T4, AM260-T4, or, AM265-T4 castings for prolonged periods at 300 to 400°F. should be avoided if the T4 properties are desired in the castings, because 20 hr. at 350°F. will convert AM240-T4 to AM240-T61 and AM260-T4 to AM260-T6, and 12 hr. at 350°F. will convert AM265-T4 to AM265-T6.

## SERVICE-FINISH RECOMMENDATIONS

Service condition	Primer	Finish
Class 1, <i>interior</i> . . .	One coat of metal primer possessing maximum adherence as shown by test. Primers containing certain of the synthetic resins, especially those of the glycerol-phthalate type, are particularly recommended. Baking usually improves adherence	One or two coats of good-quality oil paint or enamel. Lacquers may also be satisfactory under certain conditions
Class 2, <i>exterior</i> .	One coat of metal primer possessing maximum adherence as shown by test. Primers containing certain of the synthetic resins, especially those of the glycerol-phthalate type, are particularly recommended. Baking usually improves adherence	Two coats of enamels or varnishes characterized by high durability. Vehicles should be of spar varnish or contain synthetic resins of glycerol-phthalate or phenolic type. Clearspar or synthetic resin varnishes should be pigmented with 2 lb. of Albrun paste per gallon*
Class 3, <i>seaboard</i> .	One coat of zinc chromate primer meeting U. S. Army specification 14080 or Navy specification P-27. For best results, bake 30 min. to 1 hr. at 225° to 250°F.	Three coats of synthetic resin enamel of phenolic type meeting Navy specification M67 or three coats of synthetic resin varnish of phenolic type meeting Navy specification V-10 pigmented with 2 lb. of Albrun paste per gallon. For best results, bake each coat 1 hr., at 225 to 250°F.

\* The synthetic resin finishes will be improved by baking each coat for 1 hr. at 225 to 250°F.



## CHAPTER V

### STEEL

Steel in the aircraft industry plays the part of important primary structure where structural importance demands exceptional strength and rigidity. Unless specifically referred to in the following discussion, all steel referred to is not of the stainless type.

Important parts of the average military airplane made of steel are:

Engine mounts.	Wing-hinge fittings.
Frames—main stress.	Armament installations.
Welded fittings.	Motor parts.
Springs.	Bolts.
Struts.	Nuts.
Propeller blades.	Pins.
Control-surface ribs.	Gears.
Wheels.	Supports, etc.
Landing-gear parts.	

In general, where stress importance demands the inclusion of greater strength combined with resistance to constant abrasive wear and fatigue, steel is indicated. The use of steel for electrical considerations is obviated by this discussion and is not included.

Steel tubing plays a major role in aircraft production. The processing for seamless aircraft steel tubing was a major development by steel manufacturers.

Because of the fatigue and stress requirements of highly stressed parts made of steel, the steel rounds used for tubing must be practically free from inclusions and other foreign matter. Its structure must be homogeneous throughout, and its grain structure must be of the approved size.

Although other steels are listed as a possible source of "use," SAE X-4130 grade steel is indicated in practically all structural tubing. Characteristic analysis for X-4130 steel tubing shows:

Chemical Composition	Per Cent
C.....	0.27-0.33
Mn.....	0.40-0.60
P.....	0.040 max.
S.....	0.050 max.
Cr.....	0.80-1.10
Mo.....	0.15-0.25

Although other conditions are allowed, nearly all manufacturers receive tubing, bar stock, etc., in the normalized condition (90,000 p.s.i.). This allows for machining operations and subsequent forming and bending, with the specified strength ultimately demanded by the part arrived at by heat treating.

Characteristic chemical and physical compositions and properties of other appropriate steels may be found in tables 13, 14, and 15.

TABLE 13.—1025—CARBON TUBING ARMY-NAVY AERONAUTICAL SPECIFICATION  
SEAMLESS-STEEL CARBON TUBING AN-WW-T846

Chemical composition			
Carbon, per cent	Manganese, per cent	Phosphorus, maximum per cent*	Sulphur, maximum per cent
0.20-0.30	0.30-0.60	0.045	0.055
Physical properties			
Tensile strength, minimum, lb. per sq. in.	Yield strength at extension indicated		Elongation in 2 in., minimum, per cent
	Minimum, lb. per sq. in.	Extension under load, in. per in.	
55,000	36,000	0.0042	22†

\* Maximum of 0.05 per cent permitted when acid steel is specified. Physical properties shall be as specified for material in the "as furnished" condition and for material normalized by heating to 1625 to 1675°F. and cooling in still air.

† For each 2,000 lb. per square inch in excess of 55,000 lb. per square inch tensile strength, a reduction in elongation of 1 per cent to a minimum elongation of 10 per cent will be allowed.

### STRUCTURAL USE OF STEEL TUBING

The use of welded steel-tube fuselages is extended in the commercial aircraft field, and in military aviation, it is important in truss structures, monocoqued and semimonocoqued structures. The development of "tapered tubing" has definitely increased steel-tubing design technique.

Oxyacetylene welding of steel tubing is a studied technique, from the standpoint of both design and application.

Thompson and Lowe, of Vultee Aircraft (Vultee Aircraft, Inc., Downey, Calif.), in numerous papers, have published the basic technique of welding steel tubing, with particular reference to joints at the welding station. Basic technique and requirements on this subject are treated more thoroughly in subsequent portions of this book.

The Summerill Tubing Co. of Bridgeport, Pa., has made available to those interested a book prepared under the supervision of John E.

TABLE 14.—X4130—CHROME MOLYBDENUM AN-WW-T8-50 NAVY SPECIFICATION  
44-T-18C, AIR CORPS SPECIFICATION 57-180-2D

## Chemical composition\*

Carbon, per cent	Manganese, per cent	Phosphorus, maximum per cent	Sulphur, maximum per cent	Chromium, per cent	Molyb- denum, per cent
0.27-0.33	0.40-0.60	0.040	0.045	0.80-1.10	0.15-0.25

## Physical properties

Condition	Wall thickness, in.	Tensile strength, lb. per sq. in., minimum	Yield strength, lb. per sq. in., minimum	Extension under load, in. per in.	Elongation in 2 in., mini- mum per cent	
					Full tube	Strip
A. Normalized	Up to and includ- ing 0.035	95,000	75,000	0.0045	10	5
	Over 0.035 to 0.186	95,000	75,000	0.0045	12	7
	Over 0.186	90,000	70,000	0.0043	15	10
B. Heat treated	Up to 0.060	125,000	95,000	0.0052	12	7
	Over 0.060	125,000	95,000	0.0052	18	11
	Up to 0.060	150,000	112,000	0.0057	10	6
	Over 0.060	150,000	112,000	0.0057	15	9
	Up to 0.060	180,000	135,000	0.0065	8	5
	Over 0.060	180,000	135,000	0.0065	12	7
	Up to 0.060	200,000	150,000	0.0070	7	4
	Over 0.060	200,000	150,000	0.0070	11	6

\* The carbon range will be 0.27-0.33 per cent on ladle analysis. Check analysis on tubing in the range 0.25-0.33 will not be considered cause for rejection, provided that the tubing meets the physical properties specified in Table 13.

Younger, of the University of Maryland, containing much detailed and helpful information on the subject of aircraft-tubing data.

## CORROSION PROTECTION OF AIRCRAFT STEEL

According to the oxidation theory and other theories devoted to the corrosion of steel, the chemical change that is involved differs from that in aluminum alloys, although the energy—moisture—is common to both. Decomposition of steel in storage, handling, or service is a factor that must be dealt with. Prevention must be by a method both preventive and yet applicable to subsequent production operations.

Of all the theories evolved, including the acid, peroxide, colloid, and others, the electrochemical theory is the most popular and acceptable and ascribes the detrimental results most fully to moisture attack.

Oils and waxes for surface treatment of steel are generally applied to offset moisture when subsequent operations interfere with the application of a permanent or semipermanently attached coating or where ordinary organic shop coats are applied. Aluminum, lead, zinc, and other metallics are applied and carried in a suitable vehicle. The corrosion of the surface of the metal by chemical attack is well known.

TABLE 15.—X4340—CHROME-NICKEL-MOLYBDENUM, NAVY AERONAUTICAL SPECIFICATION M491

Chemical composition						
Carbon, per cent	Manga- nese, per cent	Sulphur, maximum per cent	Phospho- rus, maxi- mum per cent	Chromium, per cent	Nickel, per cent	Molyb- denum, per cent
0.35–0.40	0.50–0.80	0.050	0.040	0.60–0.90	1.50–2.00	0.20–0.30

Physical properties*				
Condi- tion†	Ultimate strength	Yield point, minimum	Percentage elongation in 2 in. minimum	
			Up to and including 3 <sup>1</sup> / <sub>16</sub> in. W.T.	Above 3 <sup>1</sup> / <sub>16</sub> in. W.T.
A	150,000 p.s.i. (normalized)	120,000 p.s.i.	5	7
B	200,000 p.s.i.	170,000 p.s.i.	4	6
C	230,000 p.s.i.	200,000 p.s.i.	3	5
D	Annealed—physical properties waived			

\* The physical properties of the steel shall be as specified when the steel is quenched in oil from 1525 to 1575°F. and suitably tempered. Normalizing shall be from a temperature 1575 to 1675°F.

† The tubing shall be furnished in the following conditions, as specified: (A) Normalized; (B) Heat-treated 200,000 *tensile strength*; (C) Heat-treated 230,000 *tensile strength*; (D) Annealed (all physical properties waived).

Organic inhibiting coatings are gaining wide favor. Chief among these in the aircraft industry is Zinc Chromate Primer; P27b-2 (Navy) and 14080 (Army). Although this material was originally designed for use on non-ferrous metals, many manufacturers are finding that where parts are to be eventually primed, the stock is cleaned and dipped in primer, then placed in stock. This primer coat acts as an inhibitor as well as an excellent shop coat against abrasion. It does not interfere with subsequent

welding operations, and if the tubing is welded into a structure for subsequent finishing, the preparation procedure prior to the finishing will destroy the shop coating automatically. Cost in this operation is not a factor due to the great reduction required of the primer.

Clear, unpigmented coatings of various kinds have found favor where other types of coatings interfere with subsequent operations. One most suited to general work and found by the author to be the most practiced is a combination of blown rapeseed and blown linseed oil furnished for use at about body "Z" (Gardner-Holt). This is applied at about 110°F. and when cool forms a viscous film over the metal not easily removed by handling, yet easily removed by solvent wiping or immersion in the ordinary aviation alkaline cleaners. As will be noticed, these oils are of the vegetable type and are easily saponified, therefore easily removed.

The one most important point to remember in the initial stages of preservation is to remove all traces of moisture and foreign matter from the surface before applying any type of preservative coating.

The inclusion of tool steel in this discussion does not seem warranted, inasmuch as the general application of commercial grades conforming to S.A.E. specifications is the practice.

The detail corrosion protection of structural steel parts in the airplane itself lends itself to many variations; however, all variations conform to one basic rule. *The contact between steel and dissimilar metals must be insulated at all times.* This insulation may be done by various methods as explained. Some of these methods are as follows:

1. *By Organic Finishing Coats.*—Where steel is in contact with the higher alloyed aluminum alloys (24S, etc.) as high as five coats of zinc Chromate Primer is recommended on the faying surfaces at the interface contact. Where steel is in contact with the lower alloyed aluminum alloys (2S-3S-52S), a minimum of three coats of Zinc Chromate Primer on the faying surfaces is recommended.

2. *By Composition Inserts.*—Non-conductive inserts such as rubber, neoprene, etc., are widely used as insulators between the contact of steel and dissimilar metals. When inserts are used, a maximum of two coats of Zinc Chromate Primer on the faying surfaces of the contacting parts is recommended.

Further discussion of dissimilar contacts as well as heat-treatment procedures for applicable steels will be found in the following chapters of this book.

**PART III**  
**AIRCRAFT FABRICS AND COMPOSITIONS**



## CHAPTER VI

### FABRIC COVERS, CLOTH, TAPES, AND THREADS

The over-all fabric-construction method (covering) of airplanes preceded all-metal construction. During the development and progress of fabric attachment, application technique reached a high standard. Much research in the application of cloth coverings has been made recently; even with all-metal designs, certain portions of various types of airplanes remain fabric-covered. This is particularly true of trainers, some observers, and the smaller planes. The inclusion of fabric surfaces on all-metal construction is influenced by the designers' requirements for performance. Control surfaces on all-metal airplanes are generally found to be fabric-covered.

The use of over-all fabric covering is still favored in the commercial field among the manufacturers of pleasure craft. Finishing technique, coupled with application progress, presents in today's pleasure craft a surface that to the layman closely identifies itself in appearance with all-metal construction.

Detail technique for the fabric covering of surfaces is suggested in the following paragraphs. It must be remembered that each design modifies the technique, but basically, the application sequence and method remain the same.

First it is well to scan the characteristic materials used in fabric application shown in Table 16. Standard AN materials are given to prevent confusion in considering proprietary materials. The exclusion of other materials from Table 16 does not eliminate their use, but Table 16 establishes a standard for other materials.

**Fabric Storage.**—All materials intended for use in the fabric covering of airplanes must be stored in a dry place, protected from direct sunlight, and handled as little as possible before using. The rooms in which sewing and application are accomplished should be clean and well ventilated. The relative humidity of the application room should be within 5 per cent of the relative humidity of the room in which the subsequent organic protective coatings are to be applied.

**Dope Proofing.**—All structural parts of the airplane coming in contact with doped fabric should be suitably protected against the solvent action of subsequent organic finishing coats. Cellulose tape or sheet or aluminum foil, secured to the structural member by means of shellac or other



suitable air-drying non-hygroscopic adhesive, when applied over the regular specified finish, usually accomplishes this purpose. Other materials and methods for dope-proofing parts may be used, but test should be made to determine their effectiveness.

TABLE 16.—MATERIALS FOR USE IN FABRIC CONSTRUCTION

Purpose	Specification *	Material	Type
Covering for surfaces...	49C13	Airplane cloth	Grade A
Surface tape.....	27T14	Cotton tape	Type 1 or 11
Reinforcing patches...	CCC-D-771	Duck	Type 11, 12 oz.
Reinforcing tape.....	27T13	Cotton tape	
Inter-rib bracing.....	27T16	Cotton tape	Type 2
Machine thread.....	V-T-476	Cotton thread	No. 16-4 cord Type 1A (bobbing) Type 1B (needle), left-hand twist
Hand-sewing thread....	V-T-276	Cotton thread	No. 10-3 Type 3B, right-hand twist
Hand-sewing thread....	V-T-291	Linen thread	No. 30-3 cord, right-hand twist
Lacing cord.....	V-T-491	Linen cord	11 ply, Type B right-hand twist
Fuselage lacing cord...	49C7	Linen cord	Type A
Wax for thread and cord	52B4	Beeswax	
Sewing.....	DDD-S-751		
Dope-proofing material.	47A5	Aluminum foil	Grade A
Dope-proofing material.	53T5	Cellulose tape	Type 2
Cover fastening.....	S-92	Self-tapping screws	Type C, No. 4-40
Cover fastening.....	AN standard	Aluminum-alloy washers	AN960-D4
Drainage grommets....	AN standard	Brass	AN230-B20-B1-B5
Drainage grommets....	N.A.F. standard	Celluloid	213055-1, -2, -3
Eyelets.....	AN standard	Brass	AN240-3
Permanent nails.....	AN standard	1/4 to 1 in. Brass Steel	AN301-B18, -B20 AN301-18, -20
Temporary tacks.....	Commercial	Copper	3 oz.
Slide fasteners.....	Commercial	Non-corrodible metal	Large heavy-duty tape

\* Current with publishing date.

**Application of Covering.**—The covering should be designed and applied in such a way that the fabric, after being sewed into position, will have proper and equal tension over its entire surface. In order to stress equally each system of threads in the fabric, tension must be applied uniformly and consistently in all directions by stretching. The fabric must be applied so that the selvage edges may be used in the seams to the

fullest possible extent. Care should be taken with designing details relating to attachment of cover plates and patches and to the reinforcement of fabric openings, particularly on the upper surfaces. Openings and fabric discontinuities should be held to a minimum.

**Seams.**—All machine seams should be sewed with two rows of stitches, such as those found in Federal specification DDD-S-751, "Stitches, Seams, and Stitching." Stitch Type 301, commonly called the "lock stitch," with 8 to 10 stitches per inch, may be used as an example for all sewing. In general, all inside seams (*i.e.*, seams not occurring at edges) should be double-stitched. Plain lap seams may be used as an alternative but should be used only where selvage edges are joined. Seams for closing wing- and tail-surface coverings should be joined so that no raw edges are exposed on the outer surfaces. Stitches should be approximately  $\frac{1}{16}$  in. from the nearest edge of the seam and the two rows of stitching in each seam approximately  $\frac{1}{4}$  to  $\frac{3}{8}$  in. apart. Whenever practical, all longitudinal or fore-and-aft seams should be parallel to the line of flight. Seams should be located so that lacing will not be through any of the seams. Needles should be the smallest diameter practicable for the size thread used.

**Hand Sewing or Nailing.**—Hand sewing usually is preferable to nailing as a means of fastening and should be used wherever possible. Hand sewing or nailing usually begins where machine sewing stops and continues to a point at which machine sewing or uncut fabric is reached. For either hand sewing or nailing, the best practice is to cut the fabric so that it can be doubled under at least  $\frac{1}{2}$  in. to form a hem through which sewing or nailing may be done. Hand sewing should employ a baseball stitch, with a minimum of four stitches per inch and ends securely finished with a lock stitch and knot. Nails are applied in two rows, staggered, and spacing between nails should be approximately  $\frac{5}{8}$  in. In cases where it is necessary temporarily to position the fabric in place while hand sewing or nailing is being accomplished, it may be tacked to the wooden parts or form with 3-oz. tacks. After the permanent fastening has been made, temporary tacks must be removed by a direct pull so as not to tear or damage the fabric. If it is necessary to fasten the fabric in position around metal parts preparatory to hand sewing, one or two wraps of adhesive tape to which the cover can be pinned may be spaced at intervals along the structure. Wooden forms may also be used. The fabric should be protected from handling abrasion on the edges of the wing structure at the root by sheathing the edges, prior to the application of the cover, with adhesive tape or airplane cloth, extending at least  $1\frac{1}{4}$  in. each way from the edges. After the cover is applied, additional protection should be provided by finishing tape, at least  $2\frac{1}{4}$  in. wide, doped on "over-all" edges and seams.

**Use of Beeswax on Thread.**—Thread for hand sewing and cord for rib lacing should be fully waxed before use. Only beeswax of the best grade should be used. The purpose of waxing is to exclude moisture during service and to protect the thread or cord against abrasion during sewing and knotting.

Hot waxed thread (thread waxed by immersion in molten beeswax) should never be used because of its inferior strength properties and its inability to absorb the dope-finishing materials. Waxing is accomplished

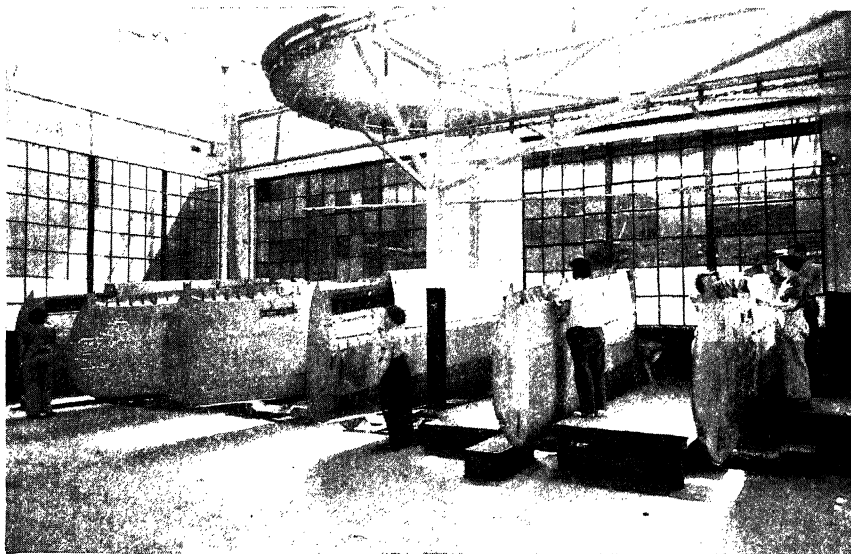


FIG. 4.—Fabric sewing operations—trailing edge of wing section.

by pulling the cord four or more times over the block of beeswax. This method of waxing will result in a weight increase of approximately 10 to 15 per cent over the weight of unwaxed cord. This process may be repeated at intervals to restore the wax coating removed by the sewing and knotting abrasion. Ends of the cord are then to be joined by a splice knot and rewaxed immediately before tying.

**Reinforcing Tape.**—Whenever covering fabric is laced to any part of the structure, reinforcing tape should be placed over the fabric along the underlying member so as to be under all lacing. The tape should be under moderate tension, except over rib capstrips, where it is pulled tight. The width of the tape should not be less than the width of the structural member to which the cover is laced. In the case of extra wide mem-

bers, two or more tapes may be used together to provide the necessary width of reinforcement, providing that satisfactory attachment can be maintained.

**Use of Surface Tape.**—Surface or finishing tape should be applied over all lacing, over all seams, and at all other places where it is necessary or desirable to provide reinforcement or to improve the finish appearance. Tape should be applied after the first coat of dope has dried. The method of doping locally over that portion of the fabric that is to be covered by the finishing tape is usually used. The tape is then laid in position on the wet dope, and a covering coat is applied immediately upon the top of the tape and over the entire surface. This latter coat, applied all over, is the second coat of the complete specified finish. Surface tape may be applied with latter coats if necessary to equalize the gloss and finished appearance of panels. Care should be taken to assure good adhesion of the pinked edges to the underlying surface by additional brushing and pressing as necessary.

**Use of Reinforcing Patches.**—All portions of fabric pierced by wires, bolts, or any other projections or holes required for oiling must be reinforced by ample patches designed to fit. Patches may be omitted, of course, where other means of reinforcing are designed. The patch should be doped on, after the first coat of dope has dried, in the same manner as tape. Where fittings protrude through the cover, filler blocks in wooden wings and plates or frames in metal wings should be fitted about them so that the fabric can be secured to the blocks or frames. A reinforcing patch should be doped on closely around the fitting for protection against the possible entrance of moisture. For either reinforcing patches or inspection doors, the patch of airplane fabric should be securely pre-sewed to the canvas or metal and should extend to not less than 1 in. beyond all sides to provide sufficient dope adhesion of patch to cover.

**Installation of Drainage Grommets.**—Grommets should be installed in all bottom surfaces in a position to provide free drainage when the airplane is in a horizontal flying attitude or when it is at rest with its tail on the ground or in the case of flying boats when the airplane is normally positioned on its beaching gear or on the water. Metal grommets should be mounted on a fabric patch commensurate with its size, which should be doped on in the same manner as reinforcing patches. Eyelets may be used in place of grommets on small surfaces. Celluloid grommets may be used with dope in the same manner as finishing tape. After the dope has thoroughly dried, the fabric in way of the grommet hole may be removed. For lower surfaces of seaplanes, amphibians, or flying boats that may be subject to spray, a special shielded grommet with hood opening aft should be designed. It should be applied either alone or in combination with a standard grommet to deflect salt water or spray from the drainage open-

ings. Care should be taken that the holes in grommets or eyelets are open.

All airfoils should have drainage grommets on the underside of the airfoil, at the trailing edge, and as close to the rib as practicable. There should be a grommet on each side of the rib to ensure good drainage. Celluloid washers from 0.030 to 0.050 in. in thickness are standard.

**Details of Airfoil Covering.** *Inter-rib Bracing.*—Inspection prior to closing in should include the alignment of ribs before wings are covered. Ribs of wings that do not have permanent inter-rib bracing should be securely braced in position to resist shifting during or subsequent to application of covers by means of cotton tape or by some other satisfactory means. If tape bracing is used, it should be applied to both the top and bottom capstrips and should be maintained parallel to the plane of the cover rather than diagonally between top and bottom capstrips. Tape must be continuous, with one to two turns around successive capstrips, arranged so that the tape between ribs is separated from the cover by a distance equal to the depth of the capstrip. The loop around each capstrip should be tied off in permanent position by means of a short length of lacing cord.

*Chafing Strips and Patches.*—In all cases where the fabric cover is likely to come in contact with sharp edges of wooden or metal spars, it must be protected from wear by the prior application of a strip of airplane cloth extending over the edge of the spar approximately 1 in. on each side and should be stretched tightly between successive rib capstrips. Chafing strips must be secured to wooden members by nailing. Similar protection from sharp edges on metal wings may be made by the use of adhesive tape secured to the underlying structure by dope or other suitable adhesive. Lacing should never be applied to structure members over a radius less than 0.030 in. All such small radii should be covered with cellulose tape or other insulating means to prevent edges from bearing on the lacing cord.

Wherever adhesive tape or cellulose tape is applied to capstrips, it must be placed under the aluminum foil or other dope proofing to avoid adhesion of the doped cover fabric to the capstrip. Where rivet heads might protrude on the leading-edge fairing, the cover fabric should be protected from chafing by suitable patches. Where rivet heads are numerous and extend over the full span, cellulose tape or airplane cloth secured in place by a suitable adhesive may be applied over the entire surface of the leading-edge sheathing.

*Application of the Cover.*—The method of applying a fabric cover will vary with different types and sizes of airfoils. Where the cord of the section to be covered is less than the width of the fabric, the covering may be applied in the seamless form. When the cord of the section is greater

than the width of the fabric, the covering should be applied in the longitudinal seam form.

*The "Seamless Form."*—The fabric cover is applied with the filling threads parallel to the line of flight or at right angles to the leading edge in the case of sweepback or taper. The seams joining top and bottom covering should be placed at the trailing edges only.

*The "Envelope Method."*—The envelope method of covering is accomplished by sewing together widths of fabric cut to specific dimensions and machine-sewed to form an envelope that can be drawn over the frame.

The outer edges of the covering should be machined-sewed unless the frame is not favorably shaped for such sewing, in which case the fabric may be joined by hand sewing, as described herein for the blanket covering.

*The "Blanket Method."*—The blanket method of covering is accomplished by sewing together widths of fabric of sufficient lengths to form a "blanket" covering for all surfaces of the frame. The trailing and outer edges of the cover are joined by using a baseball stitch of the overthrow type.

In fabricating both the envelope and blanket coverings, the fabric is cut in lengths sufficient to pass completely around the frame, starting at the trailing and returning to the trailing edge. The only seam along the span is at the trailing edge. The fabric is then joined by hand sewing at the inner and outer ends of the frame, recesses, hinges, or other obstructions that make it impracticable to draw a machine-sewed envelope over the frame.

*The "Combination Method."*—In cases where obstructions or recesses in an airfoil prevent the application of an envelope, a combination method may be employed. The envelope method should be used on as much of the span as possible and the blanket method used on the remainder. In all cases, longitudinal seams joining widths of fabric are machined-sewed.

*The Inclusion of Reinforcing Tape.*—Reinforcing tape must be placed over all capstrips prior to lacing the cover to the structure. Care is to be given that the width of reinforcing tape used is equal to the width of the capstrip in all applications. The tape used should be continuous from the trailing edge forward around the nose and back to the trailing edge. Tape then is stretched tight and the tension maintained by tying off the ends with a short piece of cord, which is to be left intact during lacing and until the first coat of dope has dried, after which the ends of the tape are cut off.

*Anti-tear Strips.*—Anti-tear strips are used over the fabric of the cover and under the standard reinforcing tape on top surfaces of both upper and lower wings and on bottom surfaces in the slipstream area of all high-performance airplanes. Use of strips on the bottom surface outside the

slipstream is usually optional. Anti-tear strips cut either straight or on the bias from airplane cloth, with edges pinked 8 to 10 pinks per inch, are normal. A greater tear resistance is afforded by the use of bias tape. Strips cut from standard airplane cloth to such width that the edges extend at least  $\frac{3}{8}$  in. outside the lines of lacing are standard. The strips are applied without any more tension than is necessary to maintain its proper position. They are then applied on a wet coat of dope, brushed on the cover along the line of the rib capstrips. Additional dope is immediately applied over the strip, and care is taken to lay the pinked edges smoothly in position. Where the anti-tear strip is on both top and bottom surfaces, it should pass continuously around the leading edge enveloping the whole rib. Where the strip is on the top surface only, it should be carried around the leading edge and back on the lower surface as far aft as the front beam. When the length is insufficient to permit one-piece application, strips may be butt-jointed, the joint being placed between lacing stitches. For purposes of this discussion, the slipstream area is defined as a strip equal in width to the propeller diameter plus one extra rib spacing on each side (two extra rib spaces in all). Use of the anti-tear strip is not necessary on tail surfaces.

*Attaching the Fabric Cover to Wing Structures.*—The cover fabric must be positively attached to the wing structure in a manner that will provide adequate strength to withstand aerodynamic loads imposed and special conditions of air turbulence where present, as in the slipstream. The method employed should lend no tendency of the dope film to crack along the lines of attachment.

*Leading-edge Covering.*—The covering procedure suggested is based on the use of a rigid leading edge, with metal sheathing positively and securely fastened to the underlying wing structure, with continuity of strength entirely around the leading edge. Where the fabric is drawn over the leading-edge sheeting, the method of application must preclude any possibility of the fabric lifting from the surface of the wing at this point. The anti-tear strip, reinforcing tape, and surface tape must be continued entirely around the leading edge. Lacing through holes drilled in the leading-edge fairing is not recommended because of the likelihood of the cords' being chafed by contact with the edges of the holes. Other standard methods, however, are acceptable to most authorities.

*Strength of Fabric Attachments.*—Attachment strength for each new design depends on factors peculiar to the case and is determined by calculations supported by test data.

*Rib Lacing.*—The lacing space for all airplanes is based on the attachment strength. Since stitch strengths are variable, depending on design, materials, and shop practice, they are usually determined by air pressure, blowoff tests of a sample fabric-to-rib attachment duplicating the

design, materials, and shop practice to be used. Outside the slipstream area, the lacing spacing may be enlarged in the aft section to take advantage of the reduced pressure existing there.

*Suggested Procedure for Characteristic Rib Lacing.*—The lacing may pass completely around both the upper and lower rib members in thin wing sections, but preference is usually given to designs in which the lacing passes around each cord member separately, provided, of course, that the capstrips are designed to take this latter type of lacing. Edges of capstrips or other structural parts to which fabric is laced should have edges rounded to a radius of approximately 0.030 or should be sheathed with adhesive tape or cellulose tape to prevent chafing of cords. Where fabric attachment points are non-uniform or are omitted because of interference of structural parts such as spars and fittings, the over-all strength nevertheless should not vary from the strength in regions of uniform attachment. Awls used for punching lacing holes should be no larger in diameter than the lacing needle ( $3\frac{1}{2}$  in. diameter, approximately) and the lacing holes placed as near to the capstrip as possible in order to minimize the tendency of the cord to start tears in the fabric. Lacing begins at the most forward stitch and progresses toward the rear, to eliminate joints in lacing cords in the region of the peak air loads. As lacing progresses, the cord should be rewaxed intermittently to restore the wax coating worn off by the sewing and knotting. Separate lengths of lacing cord may be joined by a splice knot or along the edge of the lower capstrip. The common square knot, which has a very low slippage resistance, should not be used for this purpose. Uniform tension and security of stitches are imperative. The first, or starting, stitch should be as near to the front beam as possible made with a double loop. All subsequent stitch tie-offs should be made with a single loop, with the use of standard knots for rib lacing (modified seine type). All tie-off knots should be placed on the middle of the reinforcing tape on the bottom surface. The seine knot admits a possibility of improper tightening, resulting in a false (slip) form with greatly reduced efficiency, and should not be used for stitch tie-offs. The tie-off knot for the last stitch should be locked by an additional half hitch. Where stitching ends are at the rear beam and at the trailing edge, the last two stitches should be spaced approximately at one-half normal spacing. Under no circumstances should tie-off knots be pulled back through lacing holes. In special designs where the required strength of attachment is unusually high, alternate methods of lacing may be used. These, however, should be tested.

*Surface Tape.*—Finishing or surface tapes are applied over all seams, both machine and hand-sewn, over corners, over structural members, including spars, where hard fabric wear occurs, over all lacing, along the



full length of the leading edge, around the wing tip, and along the full length of the trailing edge. Where practicable, tape along the span should be applied before the tape that extends in a fore-and-aft direction.

*Providing Openings for Inspection.*—Inspection openings, where provided in fuselage covers to permit inspection and repair of the structure, may be fabric flaps secured by either lacing or an interlocking slide fastener (such as zippers) or metal plates secured by screws or pins and hinges. To prevent the fabric being pulled out of shape when the flap or door is open, ample provision should be made for the reinforcement of the fabric in the region of the opening and the fabric sewed to the longeron adjacent to the opening. In the case of fabric flaps, finishing tape should be doped over the lacing to give a smooth-finish appearance.

## CHAPTER VII

### PHENOLIC STRUCTURAL INSULATIVE MATERIALS

Laminated and formed phenolic materials occupy a definite place in secondary structure of today's airplane. Their insulative properties and resistance to wear qualify their use in the fabrication of filler blocks, conduit and cable sheaths, pulleys, etc.

The composition of phenolic materials includes cotton fabric, paper, asbestos paper. By impregnating the base with phenolic resins, penetration is accomplished as well as bond. This bond is cured at high temperature under hydraulic pressure.

The electrical strength of fabric-based phenolic sheet is characterized by its lower power factor at high frequencies. High humidity and exposure to moisture change the insulation properties very little.

Mechanically, fabric-based phenolic sheet is one of the strongest materials per weight unit known.

Some physical properties (Phenolite Sheet—National Vulcanized Fiber) for paper and fabric-based phenolic materials are as follows:

Density.....	1.35 approximately
Specific heat.....	0.30–0.40 B.t.u. per pound
Linear-expansion coefficient.....	0.000025 per inch per degree
Thermal conductivity.....	Approximately 2 B.t.u./(sq. ft.)(hr.)(in.)(F.)

A comparison of known structural materials with phenolic sheet and similar-type compositions shows that, unlike *hard rubber*, the phenolic materials are not brittle. They machine better and are not affected by oils and solvent such as alcohol, benzol, ether, naphtha, etc. The phenolics have greater tensile strength and are not affected by corrosion due to metal contacts.

In comparison with wood, phenolic materials do not splinter, possess greater elasticity, higher dielectric strength, and are much more durable.

Compared with metals, phenolic materials, of course, offer insulating properties not obtained in metal-to-metal contacts. The chemical resistance of phenolic materials weighs heavily in their favor in replacing metal structure exposed to immersions, etc.

Fabrication notes recommended by the National Vulcanized Fibre Co. of Wilmington, Del., for their Phenolite Laminated Bakelite are characteristic process requirements for fabricating such material. However, if other materials are used, specific recommendations on the part of the vendor should be made regarding the working properties of his material.

### Circular Sawing.

*General.*—Where smooth edges and close tolerances are required.

*Saws.*—Carbon steel, tempered to permit sharpening by grinding.

*Set.*—None; hollow-ground for clearance.

*Teeth.*—6 per inch for  $\frac{1}{16}$ -in. stock; 4 per inch for  $\frac{1}{8}$  in. and over; 8 per inch for tubing.

*Saw Thickness.*— $\frac{1}{16}$  in. for  $\frac{1}{16}$ -in. stock;  $\frac{3}{32}$  in. for  $\frac{1}{8}$  in. for  $\frac{1}{4}$ -in. stock and over.

*Saw Diameter.*—12 in. diameter for  $\frac{1}{16}$ -in. stock; 14 in. diameter for  $\frac{1}{8}$ -in. stock and over; 16 in. diameter for tubing.

*Feed.*—Feed work into the saw, but do not force.

*Speed.*—From 2,700 to 3,600 r.p.m.

*Sharpening.*—Sharp point, little front rake. Grind square on cutting edge. Dull saws cause chipping, excessive heating. After sharpening, remove the burr on the side of the saw with an abrasive block.

*Tubing.*—Slowly revolve the tube while sawing for better edge and less heating.

### Band Sawing.

*General.*—Where smooth edges and close tolerances are not required.

*Saws.*—Tempered steel to permit sharpening by filing.

*Set.*—Staggered teeth used to give clearance and eliminate heating. Medium set for straight heating. Medium set for straight cuts; heavy set for circular cuts; the smaller the circle the heavier the set for clearance.

*Teeth.*—Three points per inch for material over 3 in. thick. Five points per inch for straight cuts and disks over 6 in. diameter. Six points per inch for scroll work and disks under 6 in. diameter.

*Saw Thickness.*—No. 20 gauge (0.037 in.).

*Guides.*—Keep as low as possible.

*Width.*—1 to  $1\frac{1}{4}$  in. wide for straight cuts;  $\frac{1}{2}$  in. wide for disks over 2 in. diameter;  $\frac{1}{4}$  to  $\frac{3}{8}$  in. wide for scrolls and disks under 2 in. diameter.

*Sharpening.*—Keep sharp for best results. File straight across tooth in automatic sharpeners.

*Speed.*—4,000 to 5,000 lineal ft. per minute.

*Feed.*—Feed at rate for free cutting, but do not force.

### Milling.

*Grinding.*—Cutting angle at slight rake (3 to 5 deg. more rake than for metal).

*Tools.*—High-speed or carboloy-tipped tools for large quantities.

*Speed.*—Same as for brass; 25 per cent higher than most metals. Approximately 400 ft. per minute.

*Feed.*—Same as for brass—full cut best, if possible.

NOTE: Keep cutters sharp. Dull cutters cause heat.

### Shearing.

*Shears.*—Power-operated metal squaring shears; straight knife,  $1\frac{1}{2}$ -deg. rake.

*Method.*—Punching grades up to  $\frac{1}{16}$  in. and fabric base grades up to  $\frac{3}{32}$  in. sheared cold. Other grades and thicknesses over  $\frac{1}{32}$  in. sheared hot (200 to 250°F.).

### Drilling.

*Type Drill.*—High-speed Bakelite drill best; has steeper twist, narrow web, highly polished flutes; gives more clearance for chip.

*Back-up.*—Work should be backed up with hard material for clean edges free from burs.

*Grinding.*—Grind slightly off center; otherwise hole will be 0.001 to 0.003 in. undersize. Off-center grinding lessens heating. Grind to 94-deg. point. Remove rake by grinding lips parallel to drill axis (prevents digging).

*Speed.*—Highest speed without burning; slow for larger diameters;  $\frac{1}{4}$  in. diameter, 3,000 r.p.m.;  $\frac{1}{32}$  diameter, 10,000 r.p.m. not too great.

*Feed.*—Do not force drill, especially parallel to laminations. Back out frequently to cool and to clean away chips.

*Lubricant.*—Not necessary but helps for large-diameter holes.

### Tapping.

*Tap.*—Same as for metal.

*Tap Drill.*—Slightly larger than for metal (0.003 to 0.006 in. larger).

*Lubricant.*—Slight application of light machine oil gives chips more freedom.

*Speed.*—Approximately 100 ft. per minute.

*Large Holes.*—Collapsible taps best for holes over  $1\frac{1}{2}$  in. diameter.

### Shaving.

*Dies.*—Hollow dies of desired shape—tool steel, hardened.

*Method.*—Brass or soft steel plate on ram of punch press forces material through die. Should shave off  $\frac{1}{16}$  to  $\frac{1}{8}$  in. of material per shave.

*Stock.*—Phenolite up to  $\frac{1}{8}$  in.; shave cold. Phenolite  $\frac{1}{8}$  to  $\frac{3}{8}$  in.; shave hot.

*Cutting Edge.*—45-deg. bevel—not too sharp. Best results if a trifle dull.

### Turning, Boring.

*Tools.*—Round nose—high-speed steel or carbide-tipped for quantity production.

*Feed.*—Same as for brass. Take as coarse cut as possible ( $\frac{1}{16}$  to  $\frac{1}{8}$  in.). Finishing cut, 0.010 in.

*Speed.*—Same as for brass (about 25 per cent faster than other metals). Peripheral speed 400 ft. per minute for high-speed steel and 700 ft. per minute for carboloy-tipped tools.

*Clearance.*—30 to 60 deg.; no rake.

**NOTE:** Keep tools sharp.

### Threading.

*Tools.*—High-speed steel ground as for brass, slight negative rake. Sharp chasers essential for strong, clean-cut threads.

*Methods.*—Chasing on engine lathe. Best results especially for fine threads. Self-opening die better for quantity production.

*Speed.*—Same as for brass.

*Feed.*—Same as for brass—not over 0.007 in. per cut; 0.003 in. cut to finish. Remove bur on tops of threads with file between cuts.

*Fine Threads.*—Chase in engine lathe with single V-point tool.

*Dies.*—Compound—most satisfactory die for intricate pieces. Progressive—best for high-speed fabrication.

*Speed.*—Up to 150 strokes per minute on punch press.

*Design.*—Minimum clearance between punch and die. Stripper plate should be under compression and fit punches closely.

*Dimensions.*—Punches must be made overside for hot punching, because material shrinks in cooling. Allowance depends upon thickness, temperature, size of hole.

*Example.*—For  $\frac{1}{8}$ -in. hole in  $\frac{1}{16}$ -in. stock, make punch 0.003 to 0.005 in. oversize. For  $\frac{1}{8}$ -in. hole in  $\frac{1}{8}$ -in. stock, make punch 0.012 to 0.015 in. oversize.

**Good Punching Practice.**—The following definition of good punching practice is taken from the "A.S.T.M. Tentative Specification for Phenolic Laminated Sheet for Radio Applications, D-467-37T."

In good punching practice, the edges of the piece shall not be closer to the edge of the strip than twice the thickness of the sheet; the holes shall not be smaller in diameter than the thickness of the sheet nor have square corners; the distance between holes or between holes and edge of piece shall not be less than the thickness of the sheet. Heating the material to a temperature of 120 to 140°C. (approximately 15 min. for material  $\frac{1}{8}$  in. in thickness) is generally necessary for punching results, although in some grades this may make the material too soft. In this case, better results may be obtained by heating at lower temperatures or for a shorter time. If more than 2 min. elapse between the time the strip leaves the heating medium and the last piece is punched, results will be poor.

**PART IV**  
**AIRCRAFT PROCESS MATERIALS**



## CHAPTER VIII

### CHEMICALS

The discussion of chemicals taken up in this chapter is confined to those chemicals used in production processes. Laboratory reagents, testing solutions, etc., are omitted because of their general standardization, regardless of their application to specific instance.

Commercial application of chemicals in the instance under discussion settles itself into two channels of necessary information.

1. Those chemicals commonly used.
2. Suggested sources for their procurement.

Therefore, for the purpose of ready reference, some applicable chemicals with their current governing specifications and their uses have been put into chart form in Table 17.

Suggested sources of supply on the materials found in Table 17 have been given without favor. The exclusion of other sources does not necessarily mean that their supply would not be acceptable. The sources listed are given from the author's files, which are constantly checked with instructions from the procurement sections, Army and Navy, in instructions to all manufacturers. A ready reference of acceptable sources facilitates the working and function of procurement as outlined in Chap. I. The handling and storage of industrial chemicals for process use should follow the detail instructions issued by the manufacturer, as well as the requirements of the applicable specification. The users of chemicals for processing should familiarize themselves with all safety and first-aid factors in order to safeguard property and human life.



TABLE 17.—COMMON PRODUCTION CHEMICALS USED IN AIRCRAFT PROCESSES

Material	Specification	Suggested sources of supply	Use
Acid, chromic.....	AN-C-A-81 AN-O-A-81	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	Hot chromic-dip process; anodizing processes
Acid, nitric.....	51-A-7	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	General etching and pick- ling processes
Acid, sulphuric (for storage-battery electrolyte) and gen- eral use.	O-A-111 51-A-2	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	General use, anodic elec- trolyte
Alcohol.....	4-1018-A 52-A-8	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	General solvent; shellac solvent; clean-up mate- rial
Alcohol, amyl.....	4-1047 RM-45	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	Nitrocellulose; lacquer dil- uent
Alcohol, butyl, normal.....	4-1071 RM-44	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	Nitrocellulose; lacquer and thinners
Alcohol, diacetone.....	4-21 RM-46	E. I. du Pont de Nemours & Co., Wilmington, Del. Malin Krodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	General solvent and dil- uent
Amine, alkylated tertiary phenolic.....	RM-77	Carbide & Carbon Chemical Co., New York	Stripping agents
Amyl acetate (aircraft use).....	RM-55	E. I. du Pont de Nemours & Co., Wilmington, Del. Monsanto Chemical Co., Merrimac Division, Boston, Mass.	Nitrocellulose; lacquer sol- vent; clean-up for spot welding
Antimony oxide (naval-aircraft pigment).....	RM-130-5	E. I. du Pont de Nemours & Co., Wilmington, Del.	Pigment for lacquers and enamels
Benzol.....	51B3	Michigan Alkali Co., Detroit, Mich. Harshaw Chemical Co., Cleveland, Ohio Republic Steel Co., Cleveland, Ohio	Rubber cement solvent
Borax (sodium borate).....	SS-B-611	Harshal Chemical Co., Cleveland, Ohio McKesson & Robbins Co., New York E. I. du Pont de Nemours & Co., Wilmington, Del.	Cleaning operations; neu- tralizer
Cadmium lithopone.....	RM-135	E. I. du Pont de Nemours & Co., Wilmington, Del. Visiniet-Tumpey, Inc., New York Stanley Doggett Co., New York	Pigment lacquers and enamels
Cadmium oxide, for cadmium plating.....	C-55	Udylite Corp., Detroit, Mich.	Cadmium-plating solutions

Cadmium red.....	RM-133-3	E. I. du Pont de Nemours & Co., Wilmington, Del. Wishniek-Tumpeier, Inc., New York Stanley Doggett Co., New York	Pigment enamels	lacquers and enamels
Carbon black.....	RM-131-1	E. I. du Pont de Nemours & Co., Wilmington, Del. Binney & Smith Co., New York Shawinigan Products Co., New York	Pigment enamels	lacquers and enamels
Cellulose acetate.....	RM-2	E. I. du Pont de Nemours & Co., Wilmington, Del. Nixon Nitration Works, East Nixon, N. J. Celluloid Corp., New York	Fire-retardant dopes	
Cellulose acetate.....	RM-3	E. I. du Pont de Nemours & Co., Wilmington, Del. Nixon Nitration Works, East Nixon, N. J. Celluloid Corp., New York	Fire-retardant dopes	
Cellulose acetobutyrate.....	RM-5	Hercules Powder Co., Wilmington, Del.	Fire-retardant dopes	
Cellulose nitrate.....	RM-1	E. I. du Pont de Nemours & Co., Wilmington, Del. Hercules Powder Co., Wilmington, Del. Nixon Nitration Works, East Nixon, N. J.	Nitrocellulose lacquers	
Cresol.....	RM-151	Chemical & Pigment Co., Cleveland, Ohio Reilly Tar & Chemical Co., Indianapolis, Ind. Mallinckrodt Chemical Co., St. Louis, Mo.	Germinide preservative	
Dibutylphthalate.....	RM-20	Monsanto Chemical Co., St. Louis, Mo. Amstar & Cynamid & Chemical Co., New York Carbide & Carbon Chemical Co., New York	Plasticizer; lacquer and dopes	
Dibutyl tartrate.....	RM-22	Commercial Solvents Corp., New York Kay-Fries Chemical, Inc., New York Kessler Chemical Co., New York	Plasticizer; lacquer and dopes	
Diethylene-glycol-monoethyl-ether.....	RM-85	Dow Chemical Co., Midland, Mich. Ohio-Apex Co., Nitro, W. Va.	Antifreeze	
Diethylene-glycol-monoethyl-ether.....	RM-84	Dow Chemical Co., Midland, Mich. Ohio-Apex Co., Nitro, W. Va.	Antifreeze	
Diethylene oxide.....	RM-82	Carbide & Carbon Chemical Co., New York		
Diethylphthalate.....	RM-23	Monsanto Chemical Co., St. Louis, Mo. Commercial Solvents Corp., New York U. S. Industrial Chemical Co., New York	Plasticizer; lacquer and dopes	
Dipentene.....	RM-43	Taylor, Lowenstein & Co., Mobile, Ala. Hercules Powder Co., Wilmington, Del. Southern Pine Chemical Co., Jacksonville, Fla.	Anti-skin for paints and enamels	
Ethyl acetate.....	RM-50	Ford Motor Co., Dearborn, Mich. U. S. Industrial Chemical Co., New York Merek & Co., Rahway, N. J.	Nitrocellulose solvent	

TABLE 17.—COMMON PRODUCTION CHEMICALS USED IN AIRCRAFT PROCESSES.—(Continued)

Material	Specification	Suggested sources of supply	Use
Ethyl cellosolve	RM-4	Dow Chemical Co., Midland, Mich. Hercules Powder Co., Wilmington, Del.	Lacquer ingredient (U.S.N. L-12A)
Ethylene-glycol-monoethyl-ether	RM-80	Dow Chemical Co., Midland, Mich. Ohio Chem. & Mfg., Cleveland, Ohio Carbide & Carbon Chemical Co., New York	Lacquer solvent
Ethylene-glycol-monoethyl-ether	RM-81	Dow Chemical Co., Midland, Mich. Ohio Chemical & Manufacturing, Cleveland, Ohio Carbide & Carbon Chemical Co., New York	Lacquer solvent
Glycol-sebacate	RM-21	E. I. du Pont de Nemours & Co., Wilmington, Del. Mallinckrodt Chemical Co., St. Louis, Mo.	Resin plasticizer
Naphtha, aromatic petroleum	RM-106	Phillips Petroleum Co., Detroit, Mich. Cuddeback Oil Co., Cleveland, Ohio Standard Oil, Cleveland, Ohio	Lacquer diluent clean-up
Potassium nitrate	RM-160	Mallinckrodt Chemical Co., St. Louis, Mo. J. T. Baker Chemical, North Phillipsburg, Pa.	Aluminum heat-treatment, medium
Soda, caustic, for cleaning purposes	P-S-431	Michigan Alkali, Detroit, Mich. Dow Chemical, Midland, Mich. Merek & Co., Rahway, N. J.	Cleaning
Soda, caustic, for generation of hydrogen	51-S-25	Michigan Alkali, Detroit, Mich. Dow Chemical, Midland, Mich. Merek & Co., N. J.	Preparation; hydrogen gas
Soda lime	51-S-26	Mallinckrodt Chemical Co., St. Louis, Mo.	General chemical
Sodium metasilicate	RM-140	Philadelphia Quartz Co., Philadelphia, Pa.	Cleaners
Sodium nitrate	51-S-31	E. I. du Pont de Nemours & Co., Wilmington, Del. Mallinckrodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	Aluminum heat-treatment, medium
Sodium-trisilicate, soluble, powder	RM-141	E. I. du Pont de Nemours & Co., Wilmington, Del. Mallinckrodt Chemical Co., St. Louis, Mo. Merek & Co., Rahway, N. J.	General chemical
Titanium oxide	RM-130-4	Harshaw Chemical Co., Cleveland, Ohio Wishnick Tumpeer, New York McGean Chemical Co., Cleveland, Ohio	Lacquer and enamel pigment
Titanium oxide	RM-130-6	Harshaw Chemical Co., Cleveland, Ohio Wishnick-Tumpeer, Inc., New York McGean Chemical Co., Cleveland, Ohio	Lacquer and enamel pigment
Toluene (toluol)	RM-111	Michigan Alkali, Detroit, Mich. Merek & Co., Rahway, N. J. Republic Steel, Cleveland, Ohio	Lacquer diluent; synthetic solvent
Toluoline red	RM-133-2	Sherwin-Williams, Cleveland, Ohio Calco Chemical Co., Bound Brook, N. J. National Aniline & Chemical, New York	Lacquer and enamel pigment

## CHAPTER IX

### ORGANIC FINISHES

Selection and application of organic protective coatings to military aircraft surfaces involve as much detail specification as other aircraft raw materials.

Organic protective coatings or finishes may be descriptively classified under three headings:

1. Function.
2. Composition.
3. Durability.

The function of organic finishes is the controlling factor. The intent and purpose to which a finish is to be put govern the composition and durability.

The application of organic protective coatings for military aircraft is made for a far different purpose than in any other field of transportation. These purposes may be briefly listed as follows.

1. Corrosion resistance.
2. Aid to aerodynamics.
3. Tactical aid.
4. Identification.
5. Structural aid.

This list is by no means complete, but it does serve to differentiate between finishes applied for appearance's sake and those applied as a construction necessity. Therefore, the next few paragraphs classify some of the functions of organic finishes.

Composition of various aircraft finishes, as explained, is controlled by their function. Organic chemistry has produced in the field of synthesis many new types of finishes designed particularly for each adaptation in the aircraft field. Chemical research has produced such noteworthy materials as lighter weight, more potent, inhibitive pigments; fortifying synthetic resins; chemical plasticizers for lacquers whose life is many times that of the old-type vegetable-oil plasticizers; ethyl cellulose, the sister of nitrocellulose, whose thermoplastic properties have made many advances in finishes possible. Other raw materials, too, have been contributory in this advance in finishes, but a book or many books would be required to expound their merits and place their importance.

In the preceding chapter, reference was made to the protective efficiency of various types of coatings for aluminum, magnesium, and

steel. It is perhaps best to classify the available types of finishes and their applicable efficiencies.

In this discussion, rather than to cover the entire field of protective coatings, only these directly applicable to the purpose under consideration are given.

**Nitrocellulose Lacquers.**—Nitrocellulose lacquers are composed of

1. Resin.
2. Nitrocellulose.
3. Plasticizer.
4. Solvent and diluents.
5. Pigment (if colored).

**Resin.**—The durable nitrocellulose finishes for present-day aircraft carry as their resin component members of the synthetic family such as the phenols, malcates, chlorinated diphenyls, alkyds, etc. The property of imparting gloss without the sacrifice of elasticity common of fossil resins such as ester gum, etc., characterizes this class of resins. The choice of resin is most generally dependent on the ultimate durability and use of the lacquer film.

**Nitrocellulose.**—The choice of nitrocellulose is fairly simplified because of standardization on the part of the manufacturer. The grade of nitrocellulose is chosen by viscosity of the nitrated cotton in a given standard solution. There have been many treatises published on the durability of the various viscosity grades. However, the inclusion as a component of one-half second grades is usual and universal.

**Plasticizers.**—Chemical plasticizers such as dibutyl phthalate are more or less standard. However, in this class, we must consider the "resin" plasticizers such as the glycol sebacates, so important to the formulation of dopes, etc.

**Volatile.**—Solvents for the nitrocellulose as well as the other soluble components are the main contributors to the vehicle efficiency of the lacquers. Most common of these solvents are ethyl acetate, butyl acetate, ethyl and butyl cellosolve. Propionates, amyl acetate, etc., are rarely used. The diluents include petroleum naphtha, toluol, xylol, butyl alcohol, etc.

In the practical application of lacquer finishes, it is well to remember that orthodox nitrocellulose finishes *dry by evaporation* of the volatile.

**Synthetic Enamels** (reference only to glyceryl phthalate).—Synthetic enamels, in general, are composed of

1. Resin.
2. Oils.
3. Driers.
4. Volatile.
5. Pigment (if colored).

*Resin.*—In other chapters of this book, references are made to glyceryl phthalate enamels, etc. These are the application of glyceryl phthalate resins or “alkyds,” as they are sometimes called, of the type incompatible with nitrocellulose but solvent-extendable. They act as the vehicle solids, extended by the solvents and diluents to the viscosity desired.

*Oils.*—The oil portion of the vehicle is a component part of the resin itself when being combined in the “cooking” process of the resin with the phthalic anhydride and glycerin as a fatty acid or as free oil combined by condensation.

*Driers.*—The use of metals as catalysts, to aid drying by oxidation, is made by the employment of cobalt, lead zinc, manganese, etc., in the form of naphthanate driers commercially manufactured for such purpose. These are added to the vehicle much as the other solvent components.

*Volatile.*—The volatile portion of the vehicle is directly proportionate to requirements between volatile, such as toluol, xylol, hydrogenated naphtha, mineral spirits. Common petroleum naphtha is found in some types.

In the practical application of oleoresinous or glyceryl-phthalate enamels, it is wise to bear in mind that their drying passes through three stages:

1. Evaporation of solvents.
2. Polymerization.
3. Oxidation.

The detail discussion of the various protective coatings, as explained before, is not the object here. The two outstanding types have been described that led up into the selection of one or the other and bring into position the last governing factor—*durability*.

There are many opinions on the durability of lacquer finishes versus glyceryl-phthalate materials. However, for speed of production with good durability, lacquers find favor over glyceryl-phthalate enamels. Enamels are resorted to for parts under very difficult exposure.

Recent developments have brought to light ordinarily unorthodox formulations in lacquers. Resin ratios are at a high peak, whereas nitrocellulose content is in the minority. In addition, ethyl cellulose is included. The result is a high gloss lacquer of superior elasticity and toughness plus durability approaching that of the glyceryl-phthalate enamels. Some current organic protective coatings are given in Table 17 with their use.

Dope for fabric application is most generally of the nitrate nitrocellulose type and is provided for proofing and tautening the fabric and to increase its strength. The composition of dopes does not vary far from lacquer formulations for gloss. Adhesion is much lower in dopes than in lacquers. Elasticity is the goal strived for in dopes.

TABLE 18.—REDUCTION SCHEDULES AND USES OF ORGANIC FINISHES

Type	Specification	Material, per cent	Reducer, per cent	Application operation
Army lacquer.....	3-158 colors	66.75	33.25	Spray—3-154
	Aluminum	50.00	50.00	Mix 1 lb. aluminum paste per gallon, unreduced. Spray.
	Clear	66.75	33.25	Spray—3-154.
Army primer.....	3-156	65.00	35.00	Spray—toluene (toluol)
		80.00	20.00	Dip—xylene (xylol)
Army dope.....	3-161	80.00	20.00	Spray—3-154
		No reduction required		Brush
Army dope.....	3-159	80.00	20.00	Spray—3-154
		No reduction required		Brush
Army dope.....	14096	75.00	25.00	Spray—3-154. Mix 1 lb. aluminum paste per gallon unreduced
Army dope.....	3-109E	80.00	20.00	Spray—3-154
		No reduction required		Brush
Army thinner.....	3-154		—	Use for lacquer and dope reductions
Army lacquer.....	3-163	70.00	30.00	Spray—3-154
				Light reflectors
Army Zinc Chromate Primer..	14080	66.75	33.25	Spray—toluene
		50.00	50.00	Dip—xylene (xylol); toluene (toluol)
Navy Zinc Chromate Primer...	P-27b-2	66.75	33.25	Spray—toluene
		50.00	50.00	Dip—xylene (xylol)
				T-25
Navy lacquer.....	I-12A	66.75	33.25	Spray—T-25
	Colors	66.75	33.25	Mix $\frac{1}{2}$ lb. aluminum paste per gallon unreduced
	Aluminum			Spray—T-25
	Clear	As required		T-25
Navy enamel.....	E-5	75.00	25.00	Spray—toluene
		85.00	15.00	Dip—xylene (xylol)
Navy dope.....	D-15	80.00	20.00	Spray—T-25
Navy varnish.....	V-11	90.00	10.00	Spray—toluene (toluol)
		95.00	5.00	Dip—xylene (xylol)
Navy enamel.....	E-6	80.00	20.00	Spray—toluene (toluol)
Navy thinner.....	T-25			Use for lacquer and dope reduction
Navy thinner.....	T-29			Use for antiblush retarder
Navy thinner.....	RM-111C			Toluene (toluol)
Navy rust-proof.....	RM-61	Type to be reduced as required		Par-al-Ketone
Navy soy-oil-compound.....	C-47	Use as supplied		Seam-sealing compound
Navy varnish.....	V-10	75.00	25.00	Spray—toluene (toluol)
		80.00	20.00	Dip—xylene (xylol)
AN thinner.....	TT-T-291			Mineral spirits
AN linseed oil.....	JJJ-O-331	No reduction		Raw linseed oil
AN varnish.....	TT-V-121a	90.00	10.00	Spray—toluene (toluol)
		95.00	5.00	Dip—xylene (xylol)
AN varnish.....	TT-V-81a	As required		Spray—toluene (toluol)
				Dip—xylene (xylol)
				Use as aluminum vehicle

NOTE: 14109 Army camouflage enamels and M-485 Navy camouflage lacquers have been purposely omitted owing to controversial application instructions. Manufacturers should obtain finish manufacturers' recommendations for the use of these products.

In other chapters, the detail application of the different types of organic protective coatings has been discussed. The choice of such a coating should be specific to the circumstance using the foregoing information.

The physical examination of the organic protective coating selected will do more to acquaint the user with its character than mere discussion; therefore, for the purpose of presenting methods for a physical examination, a brief outline of physical testing methods is given in the following.

#### METHODS OF TEST FOR PHYSICAL PROPERTIES OF ORGANIC FINISHES

**Working Properties.**—The material should be applied by flow or spray to smooth, clean panels of wood, metal, or fabric. When brushing is applicable, use a good, clean brush, and note whether the material shows objectionable pulling under the brush. When spray is applicable, adjust air pressure to avoid orange-peel tendencies. Observe whether the material film levels and yields a smooth surface of satisfactory appearance.

**Self-lifting Properties.**—Apply a single brush coat to a selected number of panels. At regular times, after initial coating, apply a second coating to each panel. Examine the panels for film irregularities such as blisters and pinholes and for smoothness and uniformity when viewed by reflected light.

**Non-lifting Properties.**—Apply a single brush coat of a base priming coat to an aluminum-alloy panel, and allow to dry for an allotted time. Apply a brush coat of the sample finish over the base coat, and examine after a selected time for appearance as above.

**Aluminum-vehicle Properties.**—Prepare a mixture of product and powder or paste in accordance with the directions given by the manufacturer. When adding paste to varnish, first mix the recommended amounts of turpentine and paste by intermittent stirring for 15 min. before adding to the varnish. Stir for at least 2 min.; then note the brilliance of the surface of the mixture for 1 min. after stirring. After the mixture has stood for 2 hr., stir, and apply by spraying to a clean glass panel. Examine by transmitted and reflected light for leafing properties, and note whether or not the powder distributes itself uniformly.

**Drying Properties.** *Drying Time.*—Pour or brush the material on a panel at room temperature and humidity. Place the panel in a nearly vertical position in a well-ventilated room but not in the direct rays of the sun or near heat. The film should be tested at points not less than 1 in. from the top edges. The film may be considered to have set to touch when gentle pressure of the finger shows a tacky condition but none of the material adheres to the finger. The material may be considered to have dried when the maximum pressure that can be exerted between the thumb and finger does not move the film or leave a mark that remains noticeable



after the spot is lightly polished. If rapid rubbing breaks the surface, the sample has not dried to the hard stage.

*Surface Appearance.*—The film, upon drying, should be examined in a natural light approximating north light. (“Daylite” lamps are satisfactory.)

**Color and Gloss.** *Color.*—Colored finishing materials should be compared with a standard color panel. In making comparisons for color, the material under test should be applied on a panel of material comparable to production. Sufficient coats for complete hiding are essential. After the material has dried the required time, color comparison may be made in the following manner: Both panels should be held side by side at the same angle and on the same plane so that the light reflection is the same on both. The particular angle at which they are viewed is immaterial, provided that the light reflection does not obscure the color of either. In comparing finishes of different gloss, the panels should be placed directly in front of the observer in a vertical position facing the light, with both panels wetted down with distilled water (if water does not wet sufficiently, use a heavy water-white mineral oil). This method minimizes the gloss differences as far as possible. It is practically impossible to obtain exact color matches among materials of greatly different gloss. All color comparisons should be made in a light that approximates north light at noon. Artificial light may be used, provided that the light is standardized with north light.

Sprayed panels are preferable to poured panels, because spraying usually eliminates objectionable “two-tone” effects. The comparison should be made primarily on the basis of color tone or shade. The sample should also be thoroughly examined to determine if the color is cleaner or dirtier or brighter than the standard. The sample shade should match that of the standard color in cast and tone.

#### PFUND CRYPTOMETER METHOD

**Equipment.**—The equipment consists essentially of base plates and glass wedges. The base plates have an optically flat surface, with a transverse groove in the center and a millimeter scale etched between one side of the groove and the end of the plate, a black plate being used for light colored paints and a white one for dark colored paints. The wedges are glass plates whose lower surfaces are optically flat, with tiny steel prongs protruding on one end of the underside to form a wedge when placed on a flat plate. The wedges are identified by a wedge constant  $K$ , which is the tangent of the angle formed between the wedge and a flat surface when the former is supported by its prongs.

**Operation of Equipment.**—The instrument should always be placed so that the scale to be read is on the right and the prongs of the wedge on the

left. In the case of artificial light, the light should strike (end on) at an angle of approximately 45 deg. from the left. Pour enough of the sample into the groove so that it overflows the edges. Immediately place the proper glass wedge (selected so as to give a reading of 10 to 20 mm.) on the base plate with the prongs against the optically flat surface of the plate. To make a reading, press down on the four corners of the wedge, and move this back and forth several times to press out all surplus material. Then move the wedge to the right slowly until the line of demarcation has disappeared completely over its entire length. The average of five readings will give a practical "mean setting." By referring to Table 19, the number of square feet of area hidden by 1 gal. of paint is at once determined.

*Flexibility (Cold Cracking).*—Bend a baked or aged panel rapidly through 180 deg. around a  $\frac{1}{8}$ -in. rod. For flexibility, cool to room temperature; for cold cracking, remove from an oven at bake temperature, and quickly place in a bath of melting ice. After 15 min. in the bath, bend the cold-cracking test panel immediately after removal. The film should show no evidence of cracking or loosening from the panel.

*Anchorage. Metal Anchorage.*—A film after baking should adhere to a panel surface. In being drawn down with a fine knife-edge held at a right angle to the panel, it should be difficult to lift any film from the surface, and the cut should show a fine feathered edge down to bare metal.

*Coating Anchorage (Primers).*—Spray a coat of primer on an aluminum-alloy or steel panel; bake or age; recoat by brushing on equal sections with the required recoaters. After drying hard in the normal time for the recoaters, the primer should show satisfactory anchorage of the top coats. It should be impossible to separate any of the top coats from the primer by means of a diagonally applied knife or razor blade.

*Coating Anchorage (Enamels and Lacquers).*—Spray an aluminum or steel panel in equal sections with the required primers, air 30 min. if required, and bake at 63 to 68°C. (145 to 154°F.) for 2 hr. The panel should then be recoated by brushing with the material to be tested. After drying hard in the normal time for the material, it should show satisfactory anchorage of the top coat. It should be impossible to separate any of the top coats from the primers by means of a diagonally applied knife or razor blade.

*Tautness. Calibration.*—(C. E. Sward, "Institute Paint and Varnish." This method, although usable, is not recommended for fabric finishes in production. The newer tautness meters are more applicable.) Set a "Sward hardness rocker" on a glass plate, which rests on three points. Level the plate until the pendulum of the rocker coincides with the center mark. Turn the rocker 90 deg., and again level the plate. Roll the rocker to the left until the pendulum just touches the left stop.

TABLE 19.—HIDING POWER\*  
(In square feet per gallon)

Cryptometer setting, mm.	(1) Wedge constant, 0.002	(2) Wedge constant, 0.007	(3) Wedge constant, 0.0035
5	4,070	1,163	2,326
6	3,392	969	1,938
7	2,907	831	1,662
8	2,544	727	1,454
9	2,261	646	1,292
10	2,035	581	1,162
11	1,850	529	1,058
12	1,696	485	970
13	1,565	447	894
14	1,454	415	830
15	1,357	388	776
16	1,272	363	726
17	1,197	342	684
18	1,130	323	646
19	1,071	306	612
20	1,018	291	582
21	969	277	554
22	925	264	528
23	885	253	506
24	848	242	484
25	814	233	466
26	783	224	448
27	754	215	430
28	727	208	416
29	702	200	400
30	678	194	388
31	657	188	376
32	636	182	364
33	617	176	352
34	598	171	342
35	581	166	332
36	565	162	324
37	550	157	314
38	535	153	306
39	522	149	298
40	509	145	290
41	496	142	284
42	485	138	276
43	473	135	270
44	462	132	264
45	452	129	258

This table is made from the formula

$$\text{Hiding power (square feet per gallon)} = \frac{40.745}{K \cdot XL}$$

where  $K$  = wedge constant (tangent of angle).

$L$  = scale reading (in millimeters).

\* Gardner, "Paints, Lacquer and Varnishes," National Paint, Varnish and Lacquer Association.

Gently release the rocker, and count the number of times the pendulum returns to the mark on the left side of the scale. Adjust the rocker until 50 oscillations are obtained. Glass as a standard becomes 100 per cent by multiplying the 50 by 2. The values for other materials then are

expressed directly in percentage by multiplying the number of oscillations by 2.

*Undoped Panel.*—Level an undoped fabric panel on at least three points. With the rocker obtain two readings of tautness, one parallel and the other at right angles to the warp of the fabric. The maximum reading should not exceed 12 (Navy-Army coordinate).

*Clear-dope Panel.*—Brush two and spray two successive coats of clear dope on the fabric panel, allowing each to dry at room temperature and humidity. Air-dry for the required time. Level the panel, and again test tautness with rocker.

*Pigmented Panel.*—Brush two and spray two successive coats of clear dope on the fabric panel, allowing each to dry at room temperature and humidity. Level the panel, and test for tautness with rocker. Spray or brush as specified two coats of pigmented material. Air-dry for the required time. Level the panel, and check for tautness with rocker.

**PART V**  
**STANDARD PROCESS METHODS**

## CHAPTER X

### STANDARD ALUMINUM AND ALUMINUM-ALLOY RIVETS AND METHODS FOR RIVETING

Rivet materials and their method of attachment and installation concern structure. The rivet and its uniformity of design and composition are important structure factors.

Every effort on the part of plane manufacturers is made to train sub-assemblers in the technique of riveting. Although this technique is discussed in this chapter, the information given is brief, giving only those points directly affecting production problems. On the other hand, a great deal of material detail is outlined in the following paragraphs, because large-scale production of so minute yet important a structural part is greatly affected by the tolerances and limits under which it is produced.

The conditions given under which the rivets should be produced follow very closely the military specification for such materials. Particular attention is called to the discovery showing the fixture for shear tests. A shear test on a rivet, when possible, is one of the most indicative physicals obtainable for inspection purposes.

**Grades, Types, and Classes** (from Navy 43R5d. 3-1-39).—Aluminum and aluminum-alloy rivets are furnished in the following grades and tempers for military work:

Grade 1. Aluminum, as fabricated from half-hard aluminum wire or rod.

Grade 2. Aluminum-manganese alloy, as fabricated from half-hard aluminum-manganese-alloy wire or rod.

Grade 3. Aluminum-copper-magnesium-manganese alloy, heat-treated.

Grade 4. Aluminum-copper-magnesium (1.5 per cent)-manganese alloy, heat-treated.

Grade 5. Aluminum-magnesium-silicon-chromium alloy, heat-treated.

Grade 6. Aluminum-copper-magnesium alloy, heat-treated.

Aluminum and aluminum-alloy rivets may be of the following types:

Type 1. Special oval countersunk head.

Type 2. Brazier head.

Type 3. Roundhead.

Type 4. Flathead.

Type 5. Mushroom head.

Type 6 or B-1. Buttonhead.

Type B-2. Buttonhead.

Type C-1. Countersunk head.

Type C-2. Countersunk head.

Type 7. Flat countersunk head.

Type 8. Oval countersunk head.

Aluminum and aluminum-alloy rivets for military work should be of the following classes:

Class I. For aircraft special uses.

Class II. For general use.

Rivets should be made from rivet wire or rod of a quality to ensure in the rivets full compliance with the chemical, physical, and metallographic requirements of the appliance specification. The rivets must be of uniform quality, free from seams, fins, clinch and die marks, cracks, or other injurious defects.

Rivets in grades and sizes up to  $\frac{3}{8}$  in. should be subjected to metallographic examination. Rivets that show large grain size may present difficulties in driving.

**Chemical Properties.**—The chemical composition of rivets and rivet wire and rod as determined by chemical analysis should conform with that shown in Table 20.

TABLE 20.\*—CHEMICAL COMPOSITIONS OF RIVETS

Grade	Copper, per cent	Magne- sium, per cent	Man- ganese, per cent	Chro- mium, per cent	Silicon, per cent	Iron, per cent	Zinc, per cent	Alumi- num, min. per cent
1	0.20	0.03	0.05	0.03	†	†	0.03	99.0
2	0.20	0.03	1.0-1.5	0.03	0.6	0.7	0.03	97.0
3	3.5-4.5	0.2-0.75	0.4-1.0	0.25	0.75	1.0	0.03	92.0
4	3.8-4.9	1.25-1.75	0.3-0.9	0.25	0.5	0.5	0.03	92.0
5	0.10	1.10-1.40	0.03	15-35	‡	0.35	0.03	97.0
6	2.2-2.8	0.2-0.5	0.2	0.25	0.8	1.0	0.03	95.0

\* All percentages not indicated as a range are maximum unless otherwise stated.

† Silicon plus iron, 1.0 maximum.

‡ Silicon in any sample should not be less than 45 or more than 65 per cent of the magnesium content of the sample.

**Physical Properties.** *Rivets.*—The rivets in sizes up to 0.375 in., inclusive, should have a shearing strength, calculated on the nominal diameter of the rivet, not less than the value shown in Table 21. For rivets larger than 0.375 in., a sample of the rod from which the rivets were

made should be tested and should conform to the requirements of Table 22 after being given the same heat treatment that the rivets are given. The sample must be heat-treated with the lot of rivets that it represents.

TABLE 21.—SHEAR REQUIREMENTS OF RIVETS

Grade	Alloy	Shearing strength, lb. per sq. in., min.
1	2	No shearing test required*
2	3	No shearing test required*
3	17	30,000
4	24	35,000
5	53	17,000
6	A-17	25,000

\* Grade 1 rivets to be made from Grade A rivet wire or rod and Grade B rivets to be made from Grade B rivet wire or rod.

*Rivet Wire and Rod.*—Rivet wire and rod should be of a quality and temper suitable for use in the production of rivets in standard rivet equipment. Grades 1 and 2 rivet wire and rod should conform with the requirements of Table 22. After heat treatment, Grades 3, 4, 5, and 6 rivet wire and rod shall conform with the requirements either of Table 21 or of Table 22.

TABLE 22.—PHYSICAL PROPERTIES OF RIVETS

Grade	Alloy	Diameter, in.	Tensile strength, minimum, lb. per sq. in.	Yield strength, minimum, lb. per sq. in.	Elongation, minimum, per cent in 4D*	Bend factors $N^\dagger$
1	2S	0.063–0.750	16,000	—	—	0
2	3S	0.063–0.750	19,500	—	—	1
3	17S	0.063–0.124	55,000	—	—	2
		0.125–0.750	55,000	30,000	18	4
		0.751–1.250	53,000	30,000	18	
4	24S	0.063–0.124	62,000	—	—	3
5		0.125–0.625	62,000	38,000	16	5
5	53S	0.063–0.124	25,000	—	—	2
		0.125–1.250	25,000	14,000	20	3
6	A-17	0.063–0.124	38,000	—	—	3
		0.125–0.625	38,000	18,000	18	4

\*  $D$  = diameter of the wire or rod.

† Bend-test specimens should withstand bending through an angle of 180 deg. around a mandrel having a diameter equal to  $N(N$  is the bend diameter factor) times the diameter of the specimen, without cracking.



**Tolerances in Dimensions.** *Diameter of Rivet Shanks.*—The diameter of the rivet shanks should not deviate from that specified by an amount greater than the tolerances shown in Table 23.

TABLE 23.—SHANK DIAMETER TOLERANCES

Diameter, in.	Class I rivets, in.		Class II rivets, in.	
	Minus	Plus	Minus	Plus
$\frac{1}{16}$	0.001	0.003	0.003	0.004
$\frac{3}{32}$	0.001	0.003	0.003	0.004
$\frac{1}{8}$	0.001	0.0035	0.004	0.005
$\frac{5}{32}$	0.001	0.004	0.004	0.005
$\frac{3}{16}$	0.001	0.004	0.005	0.006
$\frac{1}{4}$	0.001	0.004	0.006	0.008
$\frac{5}{16}$	0.001	0.004	0.006	0.008
$\frac{3}{8}$	0.001	0.004	0.006	0.008
$\frac{7}{16}$ — $\frac{5}{8}$	*	*	0.007	0.010
$\frac{1}{2}$ — $\frac{3}{4}$	*	*	0.009	0.012
$\frac{15}{16}$ — $1\frac{1}{4}$	*	*	*	*

\* As agreed between manufacturer and purchaser.

*Diameter of Rivet Heads.*—The diameter of Class I rivet heads should not deviate from the required diameter by an amount greater than 5 per cent (plus or minus) in rivet sizes up to  $\frac{3}{8}$  in. shank diameter; larger sizes should be agreed upon between manufacturer and the purchaser.

The diameter of Class II rivet heads should not deviate from the required diameter by an amount greater than 10 per cent (plus or minus) of the nominal diameter, in rivet sizes up to  $\frac{7}{8}$  in. shank diameter; larger sizes shall be agreed upon between the manufacturer and purchaser.

*Depth of Rivet Heads.*—The depth of the head should not deviate from the nominal thickness or depth by an amount greater than 5 per cent (plus or minus) of the nominal thickness or depth except that the tolerance must not be less than plus or minus 0.005 in. in rivet sizes up to  $\frac{7}{8}$  in. shank diameter; larger sizes should be agreed upon between the manufacturer and purchaser.

*Rivet Lengths.*—The length of Class I rivets should not deviate from the required length by more than 0.010 in. (plus or minus). The length of the rivet does not include the head except in the case of rivets having a countersunk portion of the head in rivet sizes up to  $\frac{7}{8}$  in. shank diameter; larger sizes should be agreed upon between the manufacturer and purchaser.

The length of Class II rivets should not deviate from the required length by more than plus or minus  $\frac{1}{64}$  in. in rivet sizes up to  $\frac{7}{8}$  in. shank

diameter; larger sizes should be agreed upon between manufacturer and purchaser.

*Roundness of Heads and Concentricity with Shanks.* Class I Rivets.—The heads of Class I rivets should not deviate from true roundness and concentricity with the shank by an amount that will produce a total variation in the reading of an indicator that touches the periphery of the head, as the rivet is rotated on its shank as an axis, greater than the following values:

TABLE 24

Nominal Diameter of Head, In.	Total Variation in Indicator Reading, In.
Up to 0.250, inclusive.....	0.010
Greater than 0.250–0.375.....	0.015
Greater than 0.375–0.875.....	0.020

Class II Rivets.—The heads of Class II rivets should be round and concentric with the shank within the limits of good commercial manufacturing practice.

**Production and Engineering Notes.** *Characteristic Rivet Types.*—Several different types of rivet-head forms are used in aircraft plants, viz., (1) AN standards (Army-Navy), (2) N.A.F. standards (naval aircraft factory), and (3) company standards, (aircraft company, own design), etc. The various forms of rivets discussed are:

Type	Description
(1) AN425.....	78 deg. countersunk head
(1) AN430.....	Roundhead
(1) AN442.....	Flathead
(1) AN455.....	Brazier head
(2) NAF1008.....	Universal head
(2) NAF1009.....	100 deg. countersunk head
(3) Characteristic company standard..	Special design, skin rivet head

The head dimensions supplied by the manufacturer of these rivets are contained in Fig. 5. The types of rivets discussed are available from rivet manufacturers in one or more of the following materials:

Type A. Aluminum Rivet.—This is a soft aluminum rivet for non-structural primary parts. Such rivets should not be heat-treated.

Type D. Aluminum-alloy (17ST) Rivet.—This is a medium-strength rivet having a minimum shear strength of 30,000 p.s.i. (see Table 21). Such rivets must be heat-treated before driving. For heat-treating instructions see Chap. XV.

Type DD. Aluminum-alloy (24ST) Rivet.—A high-strength rivet having a minimum shear strength of 35,000 p.s.i. (see Table 21). Such rivets must be heat-treated before driving.

**Type AD.** Aluminum-alloy (A17ST) Rivet.—A medium-strength rivet having a minimum shear strength of 25,000 p.s.i. (see Table 21). Such rivets should not be heat-treated before driving.

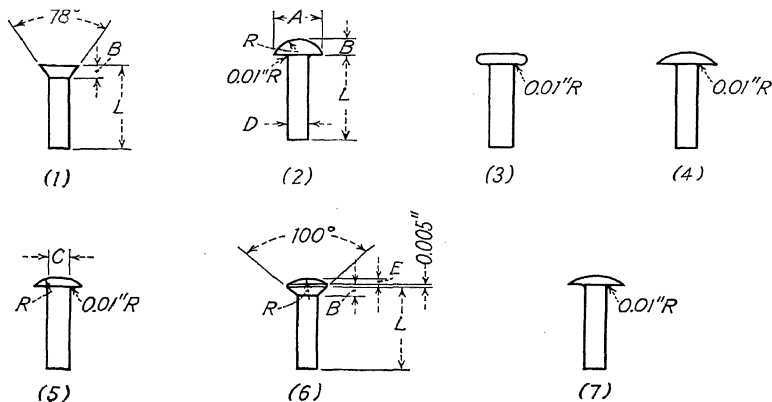


FIG. 5.

*Dimensions of manufactured heads of rivets*

No.	Code	Type	Width A	Head depth B	Head rad. R	Width C	Depth E
1	AN 425	Ctsk. head-78°	1.87 D	0.5 D			
2	AN 430	Round head	2.00 D	0.75 D	1.042 D		
3	AN 442	Flat head	2.00 D	0.4 D			
4	AN 455	Brazier head	2.50 D	0.5 D	1.813 D		
5	NAF 1008	Universal head	2.00 D	0.426 D	0.875 D	0.496 D	
6	NAF 1009	Ctsk. head-100°	1.83 D	0.348 D	8.0 D		
7	BAC 1345	Skin rivet head	2.50 D	0.416 D	2.1 D		0.053 D

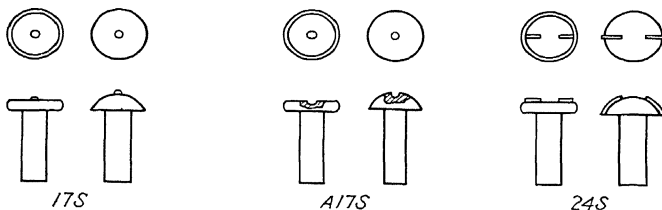


FIG. 6.—Identification markings for rivets.

The rivets discussed can be identified by the markings (or absence of markings) on the manufactured heads. The identification markings for types D (17ST), DD (24ST), and AD (A17ST) are shown in Fig. 6. When AN and N.A.F. rivets do not contain any markings on the manufactured heads, the material is aluminum (Type A). When rivets do not

contain any markings, the material should be specified in the standard book.

The rivet types discussed above are available in the following material:

- |   |  |
|---|--|
| (1) AN425 .....                         | A, D, DD, AD                                 |
| (1) AN430 .....                         | A, D, DD, AD                                 |
| (1) AN420 .....                         | A, D, DD, AD                                 |
| (1) AN455 .....                         | D, DD, AD                                    |
| (2) NAF1008 .....                       | A, D, DD                                     |
| (2) NAF1009 .....                       | A, D, DD                                     |
| (3) Characteristic company standard.... | D, DD, AD (also available in<br>monel metal) |

*Rivet Codes* (see "N.A.F. Handbook").—The basic AN or N.A.F. numbers are affixed with a letter indicating the material type (except that the "dash" is used instead of "A"), followed by a number indicating the shank diameter in thirty-seconds, followed by a dash and a number indicating the rivet's effective length (under the head for all except AN425 rivets where the over-all length is given) in sixteenths, thus:

AN425-2-2 = 78 deg. countersunk head rivet—Type A,  $\frac{1}{16}$  diameter  $\times \frac{1}{8}$  long.

AN430 D2-3 = roundhead rivet—Type D,  $\frac{1}{16}$  diameter  $\times \frac{3}{16}$  long.

AN442 DD4-6 = flathead rivet—Type DD,  $\frac{1}{8}$  diameter  $\times \frac{3}{8}$  long.

AN455 AD3-7 = brazier-head rivet—Type AD,  $\frac{3}{32}$  diameter  $\times \frac{7}{16}$  long.

NAF1008 D2-8 = universal-head rivet—Type D,  $\frac{1}{16}$  diameter  $\times \frac{1}{2}$  long.

The characteristic company standard number may be affixed with a dash letter indicating the material type (except that the letter D is omitted), followed by a number indicating the rivet's effective length in sixteenths, thus:

DAC1345-5-7 = skin-head rivet—Type D,  $\frac{5}{16}$  diameter  $\times \frac{7}{16}$  long.

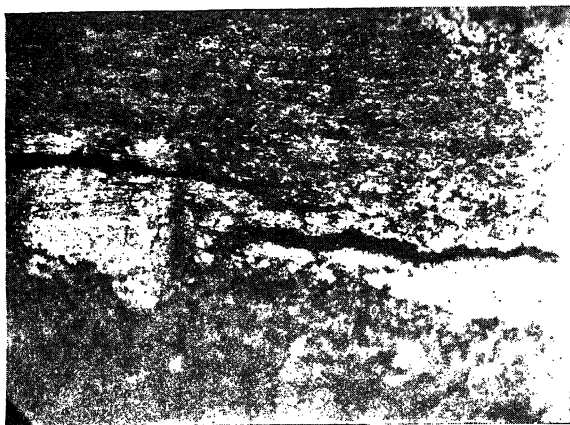
DAC1345-AD4-6 = skin-head rivet—Type AD,  $\frac{1}{8}$  diameter  $\times \frac{3}{8}$  long.

#### SUGGESTIONS IN RIVETING

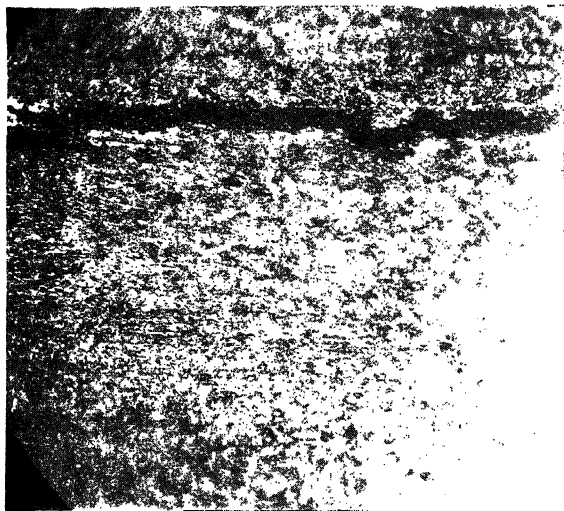
There are two basic production methods of driving aluminum and aluminum-alloy rivets, *viz.*, (1) squeezing and (2) vibrating with pneumatic hammers. The former method is preferable, because it assures properly upset shanks and well-centered heads without damaging the sheets or the manufactured heads. Other points in favor of the squeezing method are that only one man is required to drive a rivet and the necessary tools are relatively simple.

The use of machine squeezers, whether hopper-fed, which method inserts and heads the rivet in one operation, or otherwise, is the most desirable method for riveting internal structure. The multiple or gang

squeezer, which drives a number of rivets at one time, is recommended for driving external rivets of the flush type, provided, of course, that the line of rivets to be driven is not on a curve.



View 1.



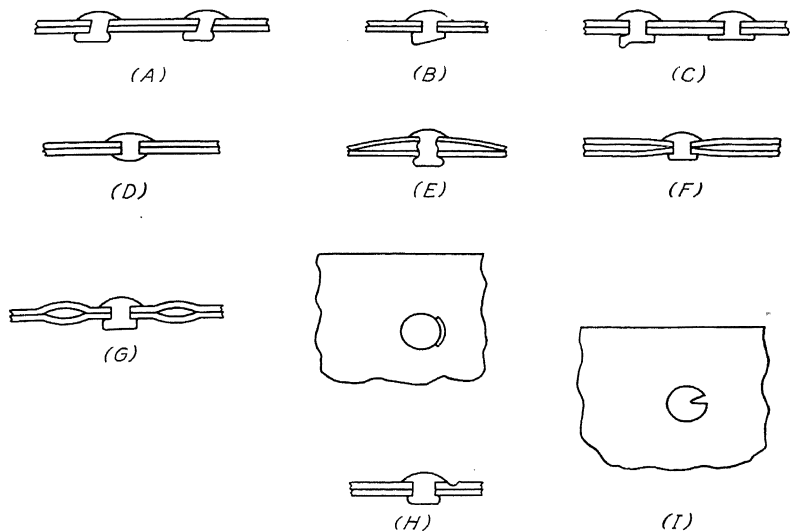
View 2.

FIG. 7.—Characteristic cracks in rivet shanks caused by flaws in the extruding die.

Bench-yoke vibrators may also be used for driving rivets. Such yokes can be operated by one man on leading-edge and wing-tip assemblies. They are lighter than the squeezers for this type of work.

Portable pneumatic squeezers can be used to advantage on assemblies that are too large to be handled conveniently by one man. These riveters are especially good for such assembling as doors, leading edges, and trailing edges.

Since vibrators are the only practical tools available for driving rivets in inaccessible places, they are used to a large extent in aircraft work.



**EXPLANATION:**

- (A) Rivet driven at slant
- (B) Rivet driven correctly, bucking tool at slant
- (C) Rivet flat on one side and too flat
- (D) Body of rivet too short, consequently closing head shaped too much with snap die
- (E) Rivet not pulled tight, clinches between plates, closing head too flat
- (F) Rivet tight, plates bulged on account of poor fit
- (G) Riveted too much. Rivet body clinched too much, plates clinched at rivet and driven apart
- (H) Riveting tool damaged plate
- (I) Head cracked account material too hard when formed

FIG. 8.—Rivet imperfections.

Such tools require the services of two men, one to operate the vibrator and one to handle the bucking block or bar. Because of the human element, this method results in more unsatisfactory rivets than any of the aforementioned methods.

The hand driving of rivets should always be reduced to an absolute minimum.

## PROCEDURES FOR RIVETING

The following procedures are recommended for driving rivets:

Inasmuch as 17ST and 24ST rivets begin to age-harden as soon as they are exposed to room temperatures after the quenching operation, it is essential that operators using these rivets do not remove more rivets from the dry ice boxes than they will use within the specified period. 17ST must not be used if exposed to room temperature for a period of 30 min. or longer, and 24ST should not be used if exposed for a period of 15 min.

TABLE 25.—CHARACTERISTIC DRILL SIZES FOR RIVETING

Rivet Diameter	Drill Size
$\frac{1}{16}$	No. 51 (0.067)
$\frac{3}{32}$	40 (0.098)
$\frac{1}{8}$	30 (0.128)
$\frac{5}{32}$	21 (0.159)
$\frac{3}{16}$	11 (0.191)
$\frac{1}{4}$	F (0.257)
$\frac{5}{16}$	O (0.316)
$\frac{3}{8}$	B (0.377)

TABLE 26.—CHARACTERISTIC NOMINAL EDGE DISTANCES FOR RIVETS  
(For aluminum-alloy rivets in aluminum-alloy sheet)

Rivet diameter, sheet, thickness, inches	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$
	Nominal distance from center of rivet to edge of sheet				
0.012	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.016	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.020	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.025	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.032	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.040	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.051	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$1\frac{3}{32}$	$\frac{1}{2}$
0.064	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{3}{8}$	$\frac{1}{2}$
0.072	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$\frac{1}{2}$
0.081	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{9}{32}$	$1\frac{1}{32}$	$\frac{1}{2}$
0.091	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{9}{32}$	$1\frac{1}{32}$	$\frac{1}{2}$
0.109	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$1\frac{1}{32}$	$\frac{1}{2}$
0.125	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{7}{16}$
0.156	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{9}{32}$	$\frac{7}{16}$
0.187	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{8}$
0.250	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$1\frac{1}{32}$
0.312	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$
0.375	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{5}{16}$
1.000	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{4}$

SPACING: The nominal space between rivet centers in any direction is equal to the values given above plus *one-half rivet diameter*.

TABLE 27.—RIVETING-EDGE MARGINS FOR ALL MATERIAL EXCEPT CASTINGS\* FOR FLUSH RIVETING IN COUNTERSUNK HOLES

Sheet thickness given in aluminum-alloy gauges. For other material use closest figure	$\frac{3}{32}$		$\frac{1}{8}$		$\frac{5}{32}$		$\frac{3}{16}$		$\frac{1}{4}$	
	Shop minimum	Design	Shop minimum	Design	Shop minimum	Design	Shop minimum	Design	Shop minimum	Design
0.040	0.17	0.24	0.24	0.32	0.30	0.38	0.37	0.46	0.50	0.60
0.051	0.15	0.22	0.21	0.28	0.29	0.36	0.37	0.46	0.50	0.60
0.057	0.15	0.22	0.21	0.28	0.28	0.34	0.37	0.46	0.50	0.60
0.064	0.15	0.22	0.20	0.26	0.25	0.32	0.34	0.42	0.50	0.60
0.072			0.19	0.26	0.23	0.30	0.31	0.40	0.50	0.58
0.081			0.19	0.26	0.23	0.30	0.29	0.38	0.47	0.56
0.091			0.19	0.26	0.23	0.30	0.27	0.36	0.40	0.54
0.102			0.19	0.26	0.23	0.30	0.27	0.36	0.40	0.50
0.125					0.23	0.30	0.27	0.36	0.36	0.46
0.156					0.23	0.30	0.27	0.36	0.35	0.44
0.188							0.27	0.36	0.35	0.44
0.250							0.27	0.36	0.35	0.44

\* Casting = edge margin: add 0.10 for castings. Add 0.20 for castings.

SPACING.—Minimum spacing between rivets in a group may be considered as the values in the preceding tables plus one-half the rivet diameter.

#### NOTES PERTAINING TO TABLE 27

1. The values given in the columns entitled Design should be used in all cases. The smaller figures in the columns entitled Shop Minimum may be given on the drawing as a shop tolerance. The shop should work as closely as possible to the full margin given, and margins below the minimum given would then be cause for inspection rejection of the parts involved. Drawings using the same edge margin and tolerance throughout for each size of rivet may give these data as a general note near the title block, preferably in combination with the legend note identifying the rivet symbols used. The following is a typical example of such a note:

"RIVET-EDGE MARGIN 0.28 MIN. 0.22"

2. Rivet margins should be dimensioned as illustrated by the typical example on drawings requiring different-edge margins throughout:

0.28  
0.22 MIN.



or longer. Rivets that have been exposed too long should be returned for reheat treatment—not placed in the dry ice boxes with the unexposed rivets.

1. It is important that the holes in the various places to be riveted together are in proper alignment.

2. The holes must be round, or nearly so, rather than elongated. When the hole size is not specified on the drawing, it may be determined from Tables 23 and 24.

3. Bucking tools must be held squarely.

4. The proper length of rivet must be used in all cases. The rivet length should be determined by actual trial or from Fig. 5.

5. It is important that edge distances of rivets be held to the dimensions shown on the pertinent prints. Tables 26 and 27 contain values for edge distances for the various projects. These tables are included as a guide only.

If ordinary care and judgment are used, proper riveting results will be obtained. Faulty rivets and the cause of the imperfections are shown in Fig. 8.

### FLUSH RIVETS

Flush rivets should be driven so that the manufactured head is not more than 0.0015 in. above the surface or more than 0.002 below the surfaces of the material being riveted.

TABLE 28.—CHARACTERISTIC AND MINIMUM DIMENSIONS OF FLAT RIVET HEADS

Rivet diameter	Head diameter		Head height	
	Desired	Minimum	Desired	Minimum
$\frac{3}{8}$	$\frac{9}{16}$	0.1250	0.063	0.0468
$\frac{1}{2}$	$\frac{3}{4}$	0.1667	0.084	0.0625
$\frac{3}{4}$	$\frac{15}{16}$	0.2083	0.105	0.0781
$\frac{7}{8}$	$\frac{1}{2}$	0.250	0.125	0.0937
$\frac{1}{4}$	$\frac{3}{8}$	0.3332	0.167	0.1250

TABLE 29.—SIZES OF ROUNDHEAD RIVETS AND APPROXIMATE NUMBER PER POUND\*

Diameter, in.	Length, in.											
	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	1
0.053	29,150	24,150	20,600	16,000	13,000	10,950	8,150	7,360	6,600	4,435	4,030	2,970
0.062	16,200	16,120	13,900	10,950	9,000	7,000	5,800	5,310	4,820	3,280	2,990	2,200
0.072	13,000	11,000	9,700	7,750	6,420	5,000	4,420	3,960	3,570	2,765	2,550	1,990
0.078	10,480	9,500	7,940	6,400	5,350	4,000	3,705	3,350	3,200	2,475	2,320	1,870
0.083	8,900	7,700	6,800	5,500	4,600	3,600	3,320	2,980	2,685	2,100	2,050	1,660
0.093	—	5,750	5,100	4,170	3,540	3,000	2,650	2,360	2,140	1,795	1,680	1,320
0.103	—	4,280	3,840	3,200	2,720	2,380	2,100	1,900	1,720	1,570	1,400	1,075
0.109	—	3,760	3,400	2,880	2,380	2,120	1,860	1,680	1,530	1,400	1,280	940
0.113	—	3,410	3,090	2,580	2,200	1,950	1,720	1,550	1,390	1,290	1,190	859
0.120	—	2,900	2,640	2,220	1,850	1,670	1,490	1,345	1,225	1,125	1,040	763
0.125	—	2,600	2,360	2,000	1,740	1,545	1,340	1,220	1,115	1,025	945	675
0.134	—	2,170	1,970	1,670	1,430	1,260	1,150	1,040	950	875	810	655
0.146	—	1,910	1,735	1,520	1,300	1,155	1,035	940	860	790	735	625
0.148	—	1,675	1,530	1,310	1,145	1,015	915	830	760	700	650	570
0.156	—	—	—	1,130	990	885	800	725	665	615	570	505
0.165	—	—	—	900	865	775	700	640	585	540	505	445
0.172	—	—	—	875	775	695	630	575	530	490	460	425
0.180	—	—	—	800	710	640	580	530	490	455	425	400
0.187	—	—	—	—	630	565	515	470	435	400	375	350
0.193	—	—	—	—	580	525	475	435	400	375	350	330
0.203	—	—	—	—	510	460	410	380	360	330	310	275
0.218	—	—	—	—	415	375	345	315	295	275	260	225
0.234	—	—	—	—	340	310	280	260	240	225	210	185
0.250	—	—	—	—	295	270	250	230	215	200	190	175
0.281	—	—	—	—	210	195	180	167	157	147	139	125
0.312	—	—	—	—	165	152	140	132	124	117	110	96
0.375	—	—	—	—	100	93	87	82	78	74	70	64
0.437	—	—	—	—	—	—	—	—	57	54	51	49
0.500	—	—	—	—	—	—	—	—	44	41	39	37
0.562	—	—	—	—	—	—	—	—	35	33	31	29
0.625	—	—	—	—	—	—	—	—	28	27	25	23
0.687	—	—	—	—	—	—	—	—	—	—	23	21
0.750	—	—	—	—	—	—	—	—	—	—	15	13
	—	—	—	—	—	—	—	—	—	—	12	11

\* Courtesy Midstate Rivets, Waupun, Wis.

TABLE 30.—COUNTERSUNK HEAD—APPROXIMATE NUMBER PER POUND

Diameter, in.	Length, in.											
	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{9}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$
0.053	49,250	37,000	28,800	20,500	15,900	13,000	11,180	9,700	8,540	5,520	5,000	4,570
0.062	33,900	25,400	20,300	14,550	11,250	9,200	8,000	7,000	6,200	4,000	3,680	3,400
0.072	23,950	18,250	14,760	10,650	8,325	6,600	5,870	5,100	4,500	3,450	3,120	2,860
0.078	19,750	15,250	12,500	8,900	7,000	5,800	5,000	4,400	3,850	3,450	3,120	2,860
0.083	17,100	13,100	10,700	7,850	6,125	5,050	4,280	3,840	3,380	3,040	2,760	2,520
0.093	—	10,200	8,850	6,100	4,800	3,950	3,270	2,450	2,000	2,340	2,140	1,940
0.103	—	7,600	6,600	4,650	3,900	3,200	2,750	2,400	2,200	1,900	1,750	1,625
0.109	—	7,000	6,000	4,300	3,400	2,800	2,400	2,150	1,880	1,680	1,530	1,400
0.113	—	6,400	5,300	3,950	3,150	2,600	2,250	1,950	1,750	1,550	1,420	1,300
0.120	—	5,560	4,640	3,500	2,780	2,320	1,980	1,740	1,530	1,380	1,260	1,130
0.125	—	5,020	4,200	3,250	2,520	2,100	1,800	1,575	1,400	1,270	1,150	1,050
0.134	—	4,250	3,560	2,700	2,160	1,800	1,550	1,360	1,210	1,090	1,000	910
0.140	—	3,830	3,220	2,500	1,970	1,650	1,410	1,250	1,110	1,000	910	835
0.148	—	3,450	2,810	2,140	1,730	1,450	1,250	1,100	980	885	805	745
0.156	—	—	—	1,900	1,540	1,300	1,130	980	880	795	720	660
0.165	—	—	—	1,620	1,350	1,140	990	870	775	705	640	590
0.172	—	—	—	1,500	1,250	1,045	915	790	715	640	590	540
0.180	—	—	—	1,370	1,110	945	815	720	640	585	535	490
0.187	—	—	—	—	1,000	870	750	660	595	540	495	450
0.193	—	—	—	—	955	805	700	615	555	500	460	420
0.203	—	—	—	—	845	720	625	555	500	450	410	380
0.218	—	—	—	—	700	600	520	465	415	380	345	320
0.234	—	—	—	—	560	465	425	375	340	310	280	265
0.250	—	—	—	—	520	430	395	360	315	285	260	240
0.281	—	—	—	—	390	335	300	265	240	220	200	185
0.312	—	—	—	—	310	270	235	215	190	175	160	150
0.375	—	—	—	—	200	175	155	140	127	117	107	100
0.437	—	—	—	—	—	—	—	—	92	86	79	73
0.500	—	—	—	—	—	—	—	—	71	66	60	56
0.562	—	—	—	—	—	—	—	—	57	52	48	45
0.625	—	—	—	—	—	—	—	—	45	42	38	36
0.687	—	—	—	—	—	—	—	—	—	—	—	—
0.750	—	—	—	—	—	—	—	—	—	—	—	—

Note: 1. Oval countersunk-head rivets—per pound approximately 10 to 15 per cent less than countersunk-head rivets.

# CHAPTER XI

## BLUEPRINT AND DRAWING DETAILS

Each person connected with the construction and fabrication of aircraft should understand the fundamentals of blueprint interpretations. Although it is not the intention of this chapter to give a detailed instruction course in blueprint reading, the common points of coordination of the designer, the fabricator, and the inspector are discussed.

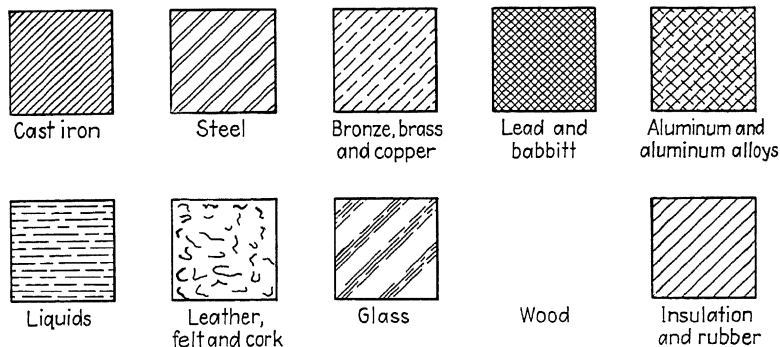


FIG. 9.—Standard cross sections of materials.



FIG. 10A.—Alternate method for all sheet metals 0.125 in. or less on detail and assembly drawings.



FIG. 10B.—Alternate method for non-metallic sheet 0.125 in. or less on detail and assembly drawings.

Standard cross sections are commonly found designating material on blueprints whose character is not explained by additional notes. The adoption of standard cross sections is universal, though every manufacturer has his own variations (see Fig. 10). AN cross sections are usually the basis upon which the variations are founded to accommodate the material used.

Standard drill and ream notes cover standard practice used by the shop in drilling, reaming, and countersinking.

## STANDARD DRILL AND REAM NOTES

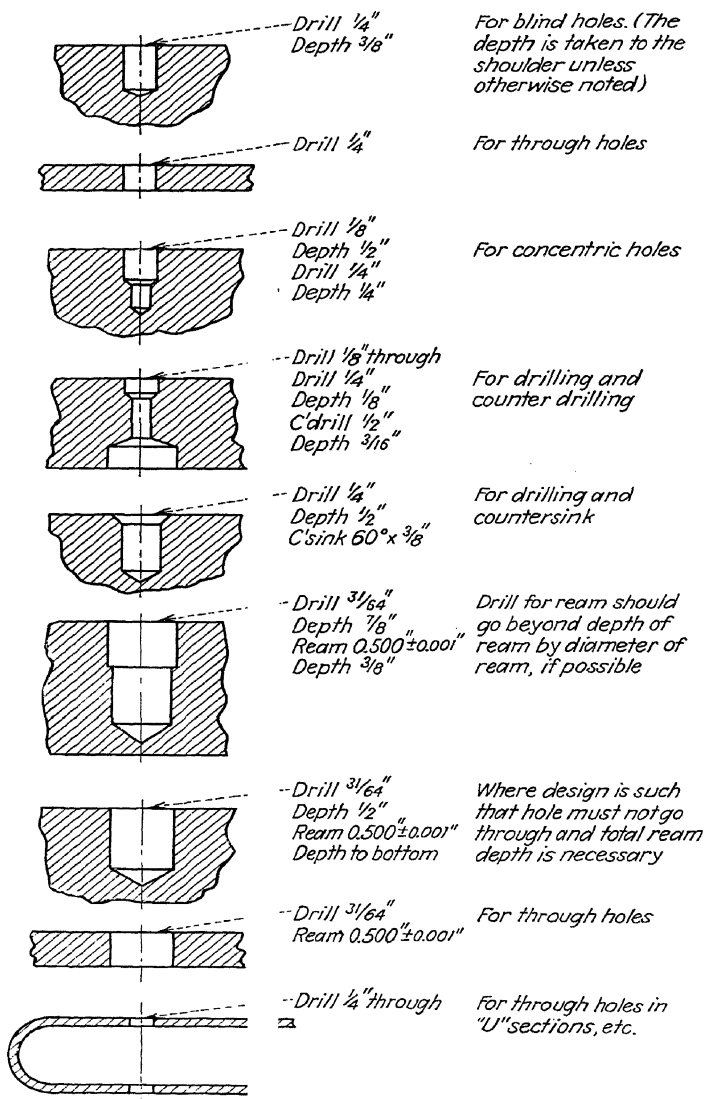


FIG. 11.

Twist-drill sizes are included as reference material, as well as tool "types." The tool working tables given are quite practicable and in the majority of cases are based on manufacturing practice and recommendations of the manufacturer of the tool itself.

Standard thread notes are included for reference only (see Fig. 12). Other standard thread notes may be found herein for standard taper pipe threads.

Assembly drawings should show sections cross-hatching to material in a manner suggested as follows. Detail drawings should show sections cross-hatched with cast-iron symbol regardless of the material.

### DRILL-POINT GRINDING<sup>1</sup>

#### SUGGESTIONS

The pointing "tips" offered here, if given consideration, will serve to eliminate the major portion of drill troubles. The best results are obtained only when drills are correctly pointed. Indifferent pointing is definitely drill abuse.

To get maximum efficiency, twist drills must be properly pointed; *i.e.*, both cutting edges should have the same inclination to the axis and be exactly the same length. For most drilling operations, 12 deg. is the correct angle at the periphery of the drill. By increasing this angle gradually toward the center of the drill, a correctly pointed drill will have been accomplished when the line across the center of the web is at an angle of approximately 135 deg. with the cutting edges. Failure to give sufficient angle of lip clearance at the center of the drill is the cause of "splitting."

When cutting edges of the drill point are ground with the same angle but of different lengths, the action will be eccentric, and the drill will cut oversize. Excessive torsional strain and unwarranted breakage result from failure to grind the cutting edges of the drill point at the same angle with the axis. Cutting edges of drill points, when ground at different angles, with the point eccentric, produce off-center holes and ragged, irregular walls.

Twist-drill failures may be traced to the following causes:

1. Chipped edges indicate excessive feed or too much lip clearance.
2. Lip-edge wear indicates excessive cutting speed.
3. Fracture causes:
  - a. Poorly ground points.
  - b. Excessive feed.

<sup>1</sup> Cogsdill Twist Drill Co., Detroit, Mich.

- c. Work holding fixture insecure; machine spindles badly worn.
  - d. Misalignment of work fixtures.
  - e. Lands worn—drill riding on heel and binding.
4. Oversize holes. Cause—careless pointing.
  5. Scored hole walls. Cause—dull drills; poor pointing.
  6. Drills throwing single chip. Cause—one side of drill point doing all the cutting.
  7. Split drills. Cause—insufficient chip clearance; excessive feed.
  8. Broken tangs. Cause—improperly fitted or worn tapers.

## STANDARD THREAD NOTES

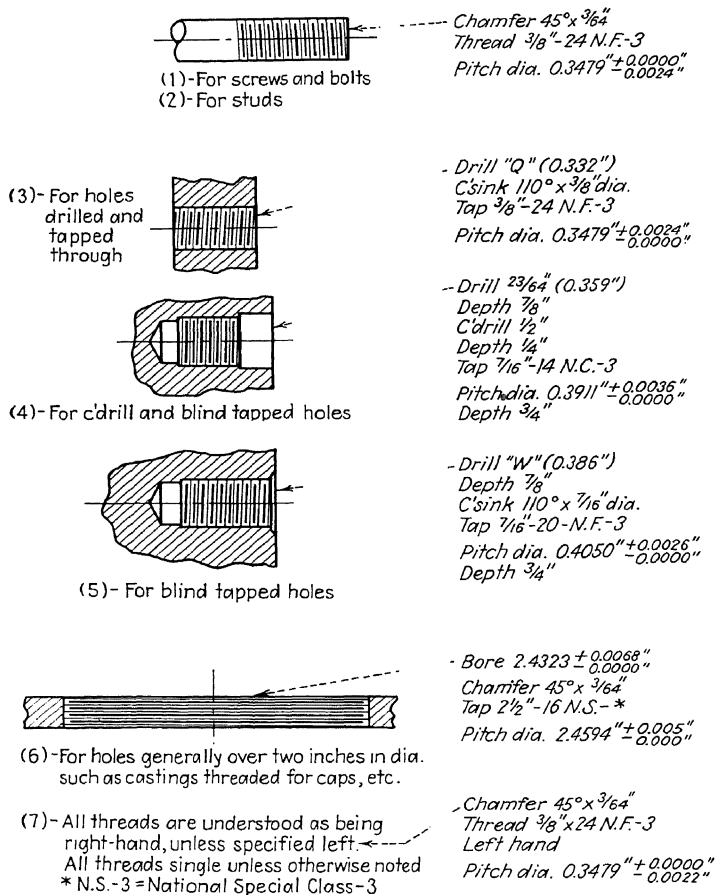


FIG. 12.

**TWIST DRILLS, THEIR PROPER SPEEDS AND FEEDS**

Often speeds and feeds are found to be excessive. The impulse to go beyond that point at which a drill is most efficient, in an effort to obtain an increase in production, seldom proves economical. It is therefore advisable to follow the chart of feeds and speeds shown in Table 31. Too many factors enter into the determination of proper combinations of feed and speeds to attempt to recommend a rule.

The right combination of speed and feed for a drill can best be determined after giving consideration to the type of drill machine, its driving mechanism, the jigs and fixtures used, and the material to be drilled. The oil or cutting compound to be used as a cooler and lubricant is also an important factor, not to be overlooked.

Table 31 is safe if the figures given are used as a starting point to determine the most effective feed and speed for a particular application.

**TABLE 31.—FEEDS FOR HIGH-SPEED STEEL DRILLS**

Sizes		Feed per revolution, in.
Up to and including $\frac{1}{4}$ in. diameter.....		0.001 –0.0045
$\frac{1}{4}$ – $\frac{1}{2}$ in. diameter.....		0.0045–0.010
Over $\frac{1}{2}$ diameter.....		0.010 –0.020

Material to be drilled	Recommended speed, ft. per min.	Recommended cooler and lubricant
Aluminum.....	250	Kerosene, kerosene and motor oil, soluble oil*
Brass.....	200	Dry, soluble oil, mineralized lard oil
Bronze.....	200	Dry, soluble oil, mineralized lard oil
Cast iron.....	120	Dry, compressed air, soluble oil
Machine steel.....	110	Soluble oil, mineralized lard oil, lard oil and sulphur
Bakelite.....	110	Dry
Malleable iron.....	85	Dry, water and sal soda
Cast iron (hard).....	80	Dry, compressed air, soluble oil
Tool steels.....	60	Mineralized lard oil, lard oil
Steel forgings.....	60	Soluble oil, mineralized lard oil
Monel metal.....	50	Lard oil, soluble oil
Stainless steel.....	30	Lard oil and sulphur
Chilled cast iron (use Trojan drills).....	20	Motor oil, dry, compressed air
Manganese steels (use Trojan drills).....	15	Dry, compressed air

To convert feet per minute (speed) into revolutions per minute,

$$(12 \times \text{feet per minute}) \div (3.1416 \times \text{drill diameter}) \quad \text{r.p.m.}$$

\* To offset the possibility of corrosion, an oil with a pH value of 6.2 to 6.7 is recommended.



TABLE 32.—VARIATION IN DIAMETER FOR GIVEN LENGTH OF TAPER

Length of tapered portion, in.	Taper per foot								
	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	1
$\frac{1}{32}$	0.0002	0.0002	0.0003	0.0007	0.0010	0.0013	0.0016	0.0020	0.0026
$\frac{1}{16}$	0.0003	0.0005	0.0007	0.0013	0.0020	0.0026	0.0033	0.0039	0.0052
$\frac{1}{8}$	0.0007	0.0010	0.0013	0.0026	0.0039	0.0052	0.0065	0.0078	0.0104
$\frac{3}{16}$	0.0010	0.0015	0.0020	0.0039	0.0059	0.0078	0.0098	0.0117	0.0156
$\frac{1}{4}$	0.0013	0.0020	0.0026	0.0052	0.0078	0.0104	0.0130	0.0156	0.0208
$\frac{5}{16}$	0.0016	0.0024	0.0033	0.0065	0.0098	0.0130	0.0163	0.0195	0.0260
$\frac{3}{8}$	0.0020	0.0029	0.0039	0.0078	0.0117	0.0156	0.0195	0.0234	0.0312
$\frac{7}{16}$	0.0023	0.0034	0.0046	0.0091	0.0137	0.0182	0.0228	0.0273	0.0365
$\frac{1}{2}$	0.0026	0.0039	0.0052	0.0104	0.0156	0.0208	0.0260	0.0312	0.0417
$\frac{9}{16}$	0.0029	0.0044	0.0059	0.0117	0.0176	0.0234	0.0293	0.0352	0.0469
$\frac{5}{8}$	0.0033	0.0049	0.0065	0.0130	0.0195	0.0260	0.0326	0.0391	0.0521
$1\frac{1}{16}$	0.0036	0.0054	0.0072	0.0143	0.0215	0.0286	0.0358	0.0430	0.0573
$\frac{3}{4}$	0.0039	0.0059	0.0078	0.0156	0.0234	0.0312	0.0391	0.0469	0.0625
$1\frac{3}{16}$	0.0042	0.0063	0.0085	0.0169	0.0254	0.0339	0.0423	0.0508	0.0677
$\frac{7}{8}$	0.0046	0.0068	0.0091	0.0182	0.0273	0.0365	0.0456	0.0547	0.0729
$1\frac{5}{16}$	0.0049	0.0073	0.0098	0.0195	0.0293	0.0391	0.0488	0.0586	0.0781
1	0.0052	0.0078	0.0104	0.0208	0.0312	0.0417	0.0521	0.0625	0.0833
2	0.0104	0.0156	0.0208	0.0417	0.0625	0.0833	0.1042	0.125	0.1667
3	0.0156	0.0234	0.0312	0.0625	0.0937	0.1250	0.1562	0.1875	0.250
4	0.0208	0.0312	0.0417	0.0833	0.125	0.1667	0.2083	0.250	0.3333
5	0.0260	0.0391	0.0521	0.1042	0.1562	0.2083	0.2604	0.3125	0.4167
6	0.0312	0.0469	0.0625	0.125	0.1875	0.250	0.3125	0.375	0.500
7	0.0365	0.0547	0.0729	0.1458	0.2187	0.2917	0.3646	0.4375	0.5833
8	0.0417	0.0625	0.0833	0.1667	0.250	0.3333	0.4167	0.500	0.6667
9	0.0469	0.0703	0.0937	0.1875	0.2812	0.375	0.4687	0.5625	0.750
10	0.0521	0.0781	0.1042	0.2083	0.3125	0.4167	0.5208	0.625	0.8333
11	0.0573	0.0859	0.1146	0.2292	0.3437	0.4583	0.5729	0.6875	0.9167
12	0.0625	0.0937	0.125	0.250	0.375	0.500	0.625	0.750	1.000
13	0.0677	0.1016	0.1354	0.2708	0.4062	0.5417	0.6771	0.8125	1.0833
14	0.0729	0.1094	0.1458	0.2917	0.4375	0.5833	0.7292	0.875	1.1667
15	0.0781	0.1172	0.1562	0.3125	0.4687	0.625	0.7812	0.9375	1.250
16	0.0833	0.125	0.1667	0.3333	0.500	0.6667	0.8333	1.000	1.3333
17	0.0885	0.1328	0.1771	0.3542	0.5312	0.7083	0.8854	1.0625	1.4167
18	0.0937	0.1406	0.1875	0.3750	0.5625	0.750	0.9375	0.125	1.500
19	0.0990	0.1484	0.1979	0.3958	0.5937	0.7917	0.9896	1.1875	1.5833
20	0.1042	0.1562	0.2083	0.4167	0.625	0.8333	1.0417	1.250	1.6667
21	0.1094	0.1641	0.2187	0.4375	0.6562	0.875	1.0937	1.3125	1.750
22	0.1146	0.1719	0.2292	0.4583	0.6875	0.9167	1.1458	1.375	1.8333
23	0.1198	0.1797	0.2396	0.4792	0.7187	0.9583	1.1979	1.4375	1.9716
24	0.125	0.1875	0.250	0.500	0.750	1.000	1.250	1.500	2.0000

TABLE 33.—THREAD DIMENSIONS AND TAP-DRILL SIZES  
American National Form Thread, Special Pitches

Size of thread and threads per in.	Major diam- eter <i>D</i> , in.	Pitch diam- eter <i>E</i> , in.	Minor diam- eter <i>K</i> , in.	Commercial tap drill to produce approxi- mately 75 % full thread	Decimal equivalent of tap drill, in.
$\frac{1}{4} \times 24$	0.2500	0.2229	0.1959	4	0.2090
$\frac{5}{16} \times 20$	0.3125	0.2800	0.2475	$1\frac{17}{64}$	0.2656
$\frac{3}{8} \times 20$	0.3750	0.3425	0.3100	$2\frac{1}{64}$	0.3281
$\frac{7}{16} \times 24$	0.4375	0.4104	0.3834	N	0.3970
$\frac{1}{2} \times 12$	0.5000	0.4459	0.3917	$2\frac{7}{64}$	0.4219
$\frac{1}{2} \times 16$	0.5000	0.4594	0.4188	$\frac{7}{16}$	0.4375
$\frac{1}{2} \times 24$	0.5000	0.4729	0.4459	$2\frac{9}{64}$	0.4531
$\frac{9}{16} \times 16$	0.5625	0.5219	0.4813	$\frac{1}{2}$	0.5000
$\frac{5}{8} \times 12$	0.6250	0.5709	0.5167	$3\frac{5}{64}$	0.5469
$\frac{5}{8} \times 16$	0.6250	0.5844	0.5438	$\frac{9}{16}$	0.5625
$1\frac{1}{16} \times 11$	0.6875	0.6285	0.5694	$1\frac{13}{32}$	0.5937
$1\frac{1}{16} \times 12$	0.6875	0.6334	0.5792	$3\frac{9}{64}$	0.6094
$\frac{3}{4} \times 12$	0.7500	0.6959	0.6417	$4\frac{3}{64}$	0.6719
$1\frac{1}{8} \times 10$	0.8125	0.7476	0.6826	$2\frac{3}{32}$	0.7187
$1\frac{1}{8} \times 12$	0.8125	0.7584	0.7042	$4\frac{7}{64}$	0.7344
$1\frac{1}{8} \times 16$	0.8125	0.7719	0.7313	$\frac{3}{4}$	0.7500
$\frac{7}{8} \times 12$	0.8750	0.8209	0.7667	$5\frac{1}{64}$	0.7969
$\frac{7}{8} \times 16$	0.8750	0.8344	0.7938	$1\frac{13}{16}$	0.8125
$1\frac{5}{16} \times 9$	0.9375	0.8653	0.7932	$5\frac{3}{64}$	0.8281
$1\frac{5}{16} \times 12$	0.9375	0.8834	0.8292	$5\frac{5}{64}$	0.8594
$1\frac{5}{16} \times 16$	0.9375	0.8969	0.8563	$\frac{7}{8}$	0.8750
1 $\times 12$	1.0000	0.9459	0.8917	$5\frac{9}{64}$	0.9219
1 $\times 16$	1.0000	0.9594	0.9188	$1\frac{5}{16}$	0.9375
$1\frac{1}{8} \times 16$	1.1250	1.0844	1.0438	$1\frac{1}{16}$	1.0625
$1\frac{1}{4} \times 16$	1.2500	1.2094	1.1688	$1\frac{3}{16}$	1.1875
$1\frac{3}{8} \times 16$	1.3750	1.3344	1.2938	$1\frac{5}{16}$	1.3125
$1\frac{1}{2} \times 16$	1.5000	1.4594	1.4188	$1\frac{7}{16}$	1.4375
$1\frac{3}{8} \times 5\frac{1}{2}$	1.6250	1.5069	1.3888	$1\frac{29}{64}$	1.4531
$1\frac{3}{4} \times 10$	1.7500	1.6850	1.6201	$1\frac{13}{32}$	1.6562
$1\frac{3}{4} \times 12$	1.7500	1.6959	1.6417	$1\frac{3}{64}$	1.6719
$1\frac{3}{4} \times 16$	1.7500	1.7094	1.6688	$1\frac{11}{16}$	1.6875
$1\frac{7}{8} \times 5$	1.8750	1.7451	1.6152	$1\frac{1}{16}$	1.6875
2 $\times 10$	2.0000	1.9350	1.8701	$1\frac{29}{32}$	1.9062
2 $\times 12$	2.0000	1.9459	1.8917	$1\frac{59}{64}$	1.9219
2 $\times 16$	2.0000	1.9594	1.9188	$1\frac{15}{16}$	1.9375
$2\frac{1}{8} \times 4\frac{1}{2}$	2.1250	1.9807	1.8363	$1\frac{29}{32}$	1.9062
$2\frac{1}{4} \times 8$	2.2500	2.1688	2.0876	$2\frac{1}{8}$	2.1250
$2\frac{1}{4} \times 12$	2.2500	2.1959	2.1417	$2\frac{11}{64}$	2.1719
$2\frac{1}{4} \times 16$	2.2500	2.2094	2.1688	$2\frac{3}{16}$	2.1875
$2\frac{3}{8} \times 4$	2.3750	2.2126	2.0502	$2\frac{1}{8}$	2.1250
$2\frac{1}{2} \times 8$	2.5000	2.4188	2.3376	$2\frac{3}{8}$	2.3750

TABLE 34.—BASIC THREAD DIMENSIONS AND TAP-DRILL SIZES\*

American National Fine Threads

(Formerly A.S.M.E. Special for sizes 0-12; S.A.E. Standard for sizes  $\frac{1}{4}$  in. and larger)

Size of thread and threads per in.	Major diam- eter <i>D</i> , in.	Pitch diam- eter <i>E</i> , in.	Minor diam- eter <i>K</i> , in.	Commercial tap drill to produce approxi- mately 75 % full thread	Decimal equivalent of tap drill, in.
0    × 80	0.0600	0.0519	0.0438	$\frac{3}{64}$	0.0469
1    × 72	0.0730	0.0640	0.0550	No. 53	0.0595
2    × 64	0.0860	0.0759	0.0657	No. 50	0.0700
3    × 56	0.0990	0.0874	0.0758	No. 45	0.0820
4    × 48	0.1120	0.0985	0.0849	No. 42	0.0935
5    × 44	0.1250	0.1102	0.0955	No. 37	0.1040
6    × 40	0.1380	0.1218	0.1055	No. 33	0.1130
8    × 36	0.1640	0.1460	0.1279	No. 29	0.1360
10   × 32	0.1900	0.1697	0.1494	No. 21	0.1590
12   × 28	0.2160	0.1928	0.1696	No. 14	0.1820
$\frac{1}{4}$ × 28	0.2500	0.2268	0.2036	No. 3	0.2130
$\frac{5}{16}$ × 24	0.3125	0.2854	0.2584	1	0.2720
$\frac{3}{8}$ × 24	0.3750	0.3479	0.3209	Q	0.3320
$\frac{7}{16}$ × 20	0.4375	0.4050	0.3725	$2\frac{5}{64}$	0.3906
$\frac{1}{2}$ × 20	0.5000	0.4675	0.4350	$2\frac{9}{64}$	0.4531
$\frac{9}{16}$ × 18	0.5625	0.5264	0.4903	$3\frac{3}{64}$	0.5156
$\frac{5}{8}$ × 18	0.6250	0.5889	0.5528	$3\frac{7}{64}$	0.5781
$\frac{3}{4}$ × 16	0.7500	0.7094	0.6688	$1\frac{1}{16}$	0.6875
$\frac{7}{8}$ × 14	0.8750	0.8286	0.7822	$1\frac{3}{16}$	0.8125
1    × 14	1.0000	0.9536	0.9072	$1\frac{5}{16}$	0.9375
$1\frac{1}{8}$ × 12	1.1250	1.0709	1.0167	$1\frac{3}{64}$	1.0469
$1\frac{1}{4}$ × 12	1.2500	1.1959	1.1417	$1\frac{1}{64}$	1.1719
$1\frac{3}{8}$ × 12	1.3750	1.3209	1.2667	$1\frac{9}{64}$	1.2969
$1\frac{1}{2}$ × 12	1.5000	1.4459	1.3917	$1\frac{7}{64}$	1.4219
$2\frac{1}{2}$ × 12	2.5000	2.4459	2.3917	$2\frac{7}{64}$	2.4219
$2\frac{1}{2}$ × 16	2.5000	2.4594	2.4188	$2\frac{1}{16}$	2.4375
$2\frac{3}{4}$ × 8	2.7500	2.6688	2.5876	$2\frac{5}{8}$	2.6250
$2\frac{3}{4}$ × 12	2.7500	2.6959	2.6417	$2\frac{5}{64}$	2.6719
$2\frac{3}{4}$ × 16	2.7500	2.7094	2.6688	$2\frac{1}{16}$	2.6875
3    × 8	3.0000	2.9188	2.8376	$2\frac{7}{8}$	2.8750
3    × $3\frac{1}{2}$	3.0000	2.8144	2.6288	$2\frac{3}{32}$	2.7187
3    × 12	3.0000	2.9459	2.8917	$2\frac{9}{64}$	2.9219
3    × 16	3.0000	2.9594	2.9188	$2\frac{5}{16}$	2.9375

\* Courtesy Cogsdill Twist Drill Co.

TABLE 35.—TABLE OF DECIMAL EQUIVALENTS OF EIGHTHS, SIXTEENTHS, THIRTY-SECONDS, AND SIXTY-FOURTHS OF AN INCH \*

Eighths	Decimal	Thirty-seconds	Decimal	Sixty-fourths	Decimal
$\frac{1}{8}$	0.125	$\frac{1}{32}$	0.03125	$\frac{1}{64}$	0.015625
$\frac{1}{4}$	0.250	$\frac{3}{32}$	0.09375	$\frac{3}{64}$	0.046875
$\frac{3}{8}$	0.375	$\frac{5}{32}$	0.15625	$\frac{5}{64}$	0.078125
$\frac{1}{2}$	0.500	$\frac{7}{32}$	0.21875	$\frac{7}{64}$	0.109375
$\frac{5}{8}$	0.625	$\frac{9}{32}$	0.28125	$\frac{9}{64}$	0.140625
$\frac{3}{4}$	0.750	$\frac{11}{32}$	0.34375	$\frac{11}{64}$	0.171875
$\frac{7}{8}$	0.875	$\frac{13}{32}$	0.40625	$\frac{13}{64}$	0.203125
Sixteenths	Decimal	$\frac{15}{32}$	0.46875	$\frac{15}{64}$	0.234375
		$\frac{17}{32}$	0.53125	$\frac{17}{64}$	0.265625
		$\frac{19}{32}$	0.59375	$\frac{19}{64}$	0.296875
		$\frac{21}{32}$	0.65625	$\frac{21}{64}$	0.328125
		$\frac{23}{32}$	0.71875	$\frac{23}{64}$	0.359375
		$\frac{25}{32}$	0.78125	$\frac{25}{64}$	0.390625
		$\frac{27}{32}$	0.84375	$\frac{27}{64}$	0.421875
		$\frac{29}{32}$	0.90625	$\frac{29}{64}$	0.453125
		$\frac{31}{32}$	0.96875	$\frac{31}{64}$	0.484375
				$\frac{33}{64}$	0.515625
				$\frac{35}{64}$	0.546875
				$\frac{37}{64}$	0.578125
				$\frac{39}{64}$	0.609375
				$\frac{41}{64}$	0.640625
				$\frac{43}{64}$	0.671875
				$\frac{45}{64}$	0.703125
				$\frac{47}{64}$	0.734375
				$\frac{49}{64}$	0.765625
				$\frac{51}{64}$	0.796875
				$\frac{53}{64}$	0.828125
				$\frac{55}{64}$	0.859375
				$\frac{57}{64}$	0.890625
				$\frac{59}{64}$	0.921875
				$\frac{61}{64}$	0.953125
				$\frac{63}{64}$	0.984375

\* Courtesy Cogsdill Twist Drill Co.

TABLE 36.—DECIMAL EQUIVALENTS OF MILLIMETERS AND FRACTIONS OF MILLIMETERS\*  
 $\frac{1}{100}$  mm. = 0.0003937 in.

Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.
$\frac{1}{50}$	0.00079	$\frac{41}{50}$	0.03228	31	1.22047	67	2.63779
$\frac{2}{50}$	0.00157	$\frac{42}{50}$	0.03307	32	1.25984	68	2.67716
$\frac{3}{50}$	0.00236	$\frac{43}{50}$	0.03386	33	1.29921	69	2.71653
$\frac{4}{50}$	0.00315	$\frac{44}{50}$	0.03465	34	1.33858	70	2.75590
$\frac{5}{50}$	0.00394	$\frac{45}{50}$	0.03543	35	1.37795	71	2.79527
$\frac{6}{50}$	0.00472	$\frac{46}{50}$	0.03622	36	1.41732	72	2.83464
$\frac{7}{50}$	0.00551	$\frac{47}{50}$	0.03701	37	1.45669	73	2.87401
$\frac{8}{50}$	0.00630	$\frac{48}{50}$	0.03780	38	1.49606	74	2.91338
$\frac{9}{50}$	0.00709	$\frac{49}{50}$	0.03858	39	1.53543	75	2.95275
$\frac{10}{50}$	0.00787	1	0.03937	40	1.57480	76	2.99212
$\frac{11}{50}$	0.00866	2	0.07874	41	1.61417	77	3.03149
$\frac{12}{50}$	0.00945	3	0.11811	42	1.65354	78	3.07086
$\frac{13}{50}$	0.01024	4	0.15748	43	1.69291	79	3.11023
$\frac{14}{50}$	0.01102	5	0.19685	44	1.73228	80	3.14960
$\frac{15}{50}$	0.01181	6	0.23622	45	1.77165	81	3.18897
$\frac{16}{50}$	0.01260	7	0.27559	46	1.81102	82	3.22834
$\frac{17}{50}$	0.01339	8	0.31496	47	1.85039	83	3.26771
$\frac{18}{50}$	0.01417	9	0.35433	48	1.88976	84	3.30708
$\frac{19}{50}$	0.01496	10	0.39370	49	1.92913	85	3.34645
$\frac{20}{50}$	0.01575	11	0.43307	50	1.96850	86	3.38582
$\frac{21}{50}$	0.01654	12	0.47244	51	2.00787	87	3.42519
$\frac{22}{50}$	0.01732	13	0.51181	52	2.04724	88	3.46456
$\frac{23}{50}$	0.01811	14	0.55118	53	2.08661	89	3.50393
$\frac{24}{50}$	0.01890	15	0.59055	54	2.12598	90	3.54330
$\frac{25}{50}$	0.01969	16	0.62992	55	2.16535	91	3.58267
$\frac{26}{50}$	0.02047	17	0.66929	56	2.20472	92	3.62204
$\frac{27}{50}$	0.02126	18	0.70866	57	2.24409	93	3.66141
$\frac{28}{50}$	0.02205	19	0.74803	58	2.28346	94	3.70078
$\frac{29}{50}$	0.02283	20	0.78740	59	2.32283	95	3.74015
$\frac{30}{50}$	0.02362	21	0.82677	60	2.36220	96	3.77952
$\frac{31}{50}$	0.02441	22	0.86614	61	2.40157	97	3.81889
$\frac{32}{50}$	0.02520	23	0.90551	62	2.44094	98	3.85826
$\frac{33}{50}$	0.02598	24	0.94488	63	2.48031	99	3.89763
$\frac{34}{50}$	0.02677	25	0.98425	64	2.51968	100	3.93700
$\frac{35}{50}$	0.02756	26	1.02362	65	2.55905		
$\frac{36}{50}$	0.02835	27	1.06299	66	2.59842		
$\frac{37}{50}$	0.02913	28	1.10236				
$\frac{38}{50}$	0.02992	29	1.14173				
$\frac{39}{50}$	0.03071	30	1.18110				
$\frac{40}{50}$	0.03150						

\* Courtesy Cogsdill Twist Drill Co.

TABLE 37.—WEIGHT PER INCH OF ROUND BARS OF CARBON AND High-speed Steel IN POUNDS PER LINEAR INCH\*

Diameter of bar, in.	Weight of bar 1 in. long		Diameter of bar, in.	Weight of bar 1 in. long		Diameter of bar, in.	Weight of bar 1 in. long	
	Carbon steel	High-speed steel		Carbon steel	High-speed steel		Carbon steel	High-speed steel
$\frac{1}{16}$	0.00087	0.00098	$1\frac{5}{16}$	0.38	0.427	$2\frac{9}{16}$	1.46	1.642
$\frac{1}{8}$	0.0035	0.0039	$1\frac{3}{8}$	0.42	0.472	$2\frac{5}{8}$	1.53	1.721
$\frac{3}{16}$	0.0078	0.0088	$1\frac{1}{4}$	0.46	0.517	$2\frac{1}{2}$	1.61	1.811
$\frac{1}{4}$	0.0139	0.0156	$1\frac{1}{2}$	0.50	0.562	$2\frac{3}{4}$	1.68	1.890
$\frac{5}{16}$	0.0217	0.0244	$1\frac{3}{16}$	0.54	0.607	$2\frac{3}{16}$	1.76	1.980
$\frac{3}{8}$	0.0313	0.0352	$1\frac{5}{8}$	0.59	0.663	$2\frac{7}{8}$	1.84	2.070
$\frac{7}{16}$	0.0425	0.0478	$1\frac{1}{2}$	0.63	0.709	$2\frac{5}{16}$	1.92	2.160
$\frac{1}{2}$	0.0556	0.0625	$1\frac{3}{4}$	0.68	0.765	3	2.00	2.250
$\frac{9}{16}$	0.0703	0.0791	$1\frac{3}{8}$	0.73	0.821	$3\frac{1}{16}$	2.08	2.340
$\frac{5}{8}$	0.0868	0.0976	$1\frac{7}{8}$	0.78	0.877	$3\frac{1}{8}$	2.17	2.441
$1\frac{1}{16}$	0.105	0.118	$1\frac{5}{16}$	0.83	0.933	$3\frac{3}{16}$	2.26	2.542
$\frac{3}{4}$	0.125	0.141	2	0.89	1.001	$3\frac{1}{4}$	2.35	2.643
$1\frac{1}{8}$	0.147	0.165	$2\frac{1}{16}$	0.94	1.057	$3\frac{5}{16}$	2.44	2.745
$\frac{7}{8}$	0.170	0.191	$2\frac{3}{8}$	1.00	1.125	$3\frac{3}{8}$	2.53	2.846
$1\frac{1}{2}$	0.195	0.219	$2\frac{3}{16}$	1.06	1.192	$3\frac{7}{16}$	2.63	2.958
1	0.22	0.248	$2\frac{1}{4}$	1.13	1.271	$3\frac{1}{2}$	2.72	3.060
$1\frac{1}{16}$	0.25	0.281	$2\frac{5}{16}$	1.19	1.338	$3\frac{9}{16}$	2.82	3.172
$1\frac{1}{8}$	0.28	0.315	$2\frac{3}{8}$	1.25	1.406	$3\frac{5}{8}$	2.92	3.285
$1\frac{3}{16}$	0.31	0.349	$2\frac{7}{16}$	1.33	1.496	$3\frac{11}{16}$	3.02	3.397
$1\frac{1}{4}$	0.35	0.397	$2\frac{1}{2}$	1.39	1.563	$3\frac{3}{4}$	3.13	3.521
$1\frac{3}{8}$	3.23	3.633	$4\frac{7}{8}$	5.23	5.940	6	8.00	9.000
$1\frac{1}{2}$	3.34	3.757	$4\frac{1}{2}$	5.42	6.097	$6\frac{1}{8}$	8.34	9.382
$1\frac{5}{8}$	3.45	3.881	5	5.56	6.255	$6\frac{1}{4}$	8.68	9.765
4	3.56	4.005	$5\frac{1}{8}$	5.70	6.412	$6\frac{3}{8}$	9.03	10.16
$4\frac{1}{16}$	3.67	4.128	$5\frac{3}{8}$	5.84	6.570	$6\frac{1}{2}$	9.39	10.56
$4\frac{1}{8}$	3.78	4.252	$5\frac{5}{16}$	5.98	6.727	$6\frac{5}{8}$	9.76	10.98
$4\frac{3}{16}$	3.90	4.387	$5\frac{1}{4}$	6.13	6.896	$6\frac{3}{4}$	10.1	11.36
$4\frac{1}{4}$	4.01	4.511	$5\frac{3}{16}$	6.27	7.053	$6\frac{7}{8}$	10.5	11.81
$4\frac{5}{16}$	4.13	4.646	$5\frac{3}{8}$	6.42	7.222	7	10.9	12.26
$4\frac{3}{8}$	4.25	4.781	$5\frac{7}{16}$	6.57	7.391	$7\frac{1}{8}$	11.3	12.71
$4\frac{7}{16}$	4.38	4.927	$5\frac{1}{2}$	6.72	7.560	$7\frac{1}{4}$	11.7	13.16
$4\frac{1}{2}$	4.50	5.062	5	6.88	7.740	$7\frac{3}{8}$	12.1	13.16
$4\frac{9}{16}$	4.63	5.208	$5\frac{5}{8}$	7.03	7.908	$7\frac{1}{2}$	12.5	14.06
$4\frac{5}{8}$	4.75	5.343	$5\frac{11}{16}$	7.19	8.088	$7\frac{5}{8}$	12.9	14.51
$4\frac{11}{16}$	4.88	5.490	$5\frac{3}{4}$	7.35	8.268	$7\frac{3}{4}$	13.3	14.96
$4\frac{3}{4}$	5.01	5.636	$5\frac{13}{16}$	7.51	8.448	$7\frac{7}{8}$	13.8	15.52
$4\frac{13}{16}$	5.15	5.793	$5\frac{7}{8}$	7.67	8.628	8	14.3	16.08
			$5\frac{15}{16}$	7.84	8.820			

\* Courtesy Cogsdill Twist Drill Co.

TABLE 38.—WEIGHTS OF ● AND ■ STEEL LINEAL FOOT\*  
(Based on 489.6 lb. per cubic foot)†

Size, in.	Weight of ● 1 ft. long	Weight of ■ 1 ft. long	Size, in.	Weight of ● 1 ft. long	Weight of ■ 1 ft. long	Size, in.	Weight of ● 1 ft. long	Weight of ■ 1 ft. long
$\frac{1}{8}$ "	0.0026	0.0033	3	24.03	30.60	6	96.14	122.4
$\frac{1}{4}$ "	0.0104	0.0133	3 $\frac{1}{8}$ "	25.04	31.89	6 $\frac{1}{8}$ "	98.14	125.0
$\frac{3}{8}$ "	0.0417	0.0531	3 $\frac{1}{4}$ "	26.08	33.20	6 $\frac{1}{4}$ "	100.2	127.6
$\frac{1}{2}$ "	0.0938	0.1195	3 $\frac{3}{8}$ "	27.13	34.55	6 $\frac{3}{8}$ "	102.2	130.2
$\frac{5}{8}$ "	0.1669	0.2123	3 $\frac{1}{2}$ "	28.20	35.92	6 $\frac{1}{2}$ "	104.3	132.8
$\frac{3}{4}$ "	0.2608	0.3333	3 $\frac{5}{8}$ "	29.30	37.31	6 $\frac{5}{8}$ "	106.4	135.5
$\frac{7}{8}$ "	0.3756	0.4782	3 $\frac{7}{8}$ "	30.42	38.73	6 $\frac{7}{8}$ "	108.5	138.2
$1$ "	0.5111	0.6508	3 $1$ "	31.56	40.18	6 $1$ "	110.7	140.9
$1 \frac{1}{8}$ "	0.6676	0.8500	3 $1 \frac{1}{8}$ "	32.71	41.65	6 $1 \frac{1}{8}$ "	112.8	143.6
$1 \frac{1}{4}$ "	0.8449	1.076	3 $1 \frac{1}{4}$ "	33.90	43.14	6 $1 \frac{1}{4}$ "	114.9	146.5
$1 \frac{3}{8}$ "	1.043	1.328	3 $1 \frac{3}{8}$ "	35.09	44.68	6 $1 \frac{3}{8}$ "	117.2	149.2
$1 \frac{1}{2}$ "	1.262	1.608	3 $1 \frac{1}{2}$ "	36.31	46.24	6 $1 \frac{1}{2}$ "	119.4	152.1
$1 \frac{3}{4}$ "	1.502	1.913	3 $1 \frac{3}{4}$ "	37.56	47.82	6 $1 \frac{3}{4}$ "	121.7	154.9
$1 \frac{7}{8}$ "	1.763	2.245	3 $1 \frac{7}{8}$ "	38.81	49.42	6 $1 \frac{7}{8}$ "	123.9	157.8
$2$ "	2.044	2.603	3 $2$ "	40.10	51.05	6 $2$ "	126.2	160.8
$2 \frac{1}{8}$ "	2.347	2.989	3 $2 \frac{1}{8}$ "	41.40	52.71	6 $2 \frac{1}{8}$ "	128.5	163.6
$2 \frac{1}{4}$ "	2.670	3.400	4	42.73	54.40	7	130.9	166.6
$2 \frac{3}{8}$ "	3.014	3.833	4 $\frac{1}{8}$ "	44.07	56.11	7 $\frac{1}{8}$ "	135.6	172.6
$2 \frac{1}{2}$ "	3.379	4.303	4 $\frac{1}{4}$ "	45.44	57.85	7 $\frac{1}{4}$ "	140.4	178.7
$2 \frac{3}{4}$ "	3.766	4.795	4 $\frac{3}{8}$ "	46.83	59.62	7 $\frac{3}{8}$ "	145.3	184.9
$2 \frac{7}{8}$ "	4.173	5.312	4 $\frac{1}{2}$ "	48.24	61.41	7 $\frac{1}{2}$ "	150.2	191.3
$3$ "	4.600	5.857	4 $\frac{5}{8}$ "	49.66	63.23	7 $\frac{5}{8}$ "	155.2	197.7
$3 \frac{1}{8}$ "	5.019	6.428	4 $\frac{3}{4}$ "	51.11	65.08	7 $\frac{3}{4}$ "	160.3	204.2
$3 \frac{1}{4}$ "	5.518	7.026	4 $1$ "	52.58	66.95	8 $\frac{1}{8}$ "	165.5	210.8
$3 \frac{3}{8}$ "	6.008	7.650	4 $1 \frac{1}{8}$ "	54.07	68.85	8 $\frac{1}{4}$ "	171.0	217.6
$3 \frac{1}{2}$ "	6.520	8.301	4 $1 \frac{1}{4}$ "	55.59	70.78	8 $\frac{1}{2}$ "	176.3	224.5
$3 \frac{3}{4}$ "	7.051	8.978	4 $1 \frac{3}{8}$ "	57.12	73.73	8 $\frac{3}{8}$ "	181.8	231.4
$3 \frac{7}{8}$ "	7.604	9.682	4 $1 \frac{1}{2}$ "	58.67	74.70	8 $\frac{1}{2}$ "	187.3	238.5
$4$ "	8.178	10.41	4 $1 \frac{3}{4}$ "	60.25	76.71	8 $1$ "	193.0	245.6
$4 \frac{1}{8}$ "	8.773	11.17	4 $1 \frac{7}{8}$ "	61.84	78.74	8 $1 \frac{1}{8}$ "	198.7	252.9
$4 \frac{1}{4}$ "	9.388	11.95	4 $2$ "	63.46	80.81	8 $1 \frac{1}{4}$ "	204.4	260.3
$4 \frac{3}{8}$ "	10.02	12.76	4 $2 \frac{1}{8}$ "	65.10	82.89	8 $1 \frac{3}{8}$ "	210.3	267.9
$4 \frac{1}{2}$ "	10.68	13.60	5	66.76	85.00	9	216.3	275.4
$4 \frac{3}{4}$ "	11.36	14.46	5 $\frac{1}{8}$ "	68.44	87.14	9 $\frac{1}{8}$ "	222.4	283.2
$4 \frac{7}{8}$ "	12.06	15.35	5 $\frac{1}{4}$ "	70.14	89.30	9 $\frac{1}{4}$ "	228.5	291.1
$5$ "	12.78	16.27	5 $\frac{3}{8}$ "	71.86	91.49	9 $\frac{3}{8}$ "	234.7	298.9
$5 \frac{1}{8}$ "	13.52	17.22	5 $\frac{1}{2}$ "	73.60	93.72	9 $\frac{1}{2}$ "	241.0	306.8
$5 \frac{1}{4}$ "	14.28	18.19	5 $\frac{3}{4}$ "	75.37	95.96	9 $\frac{3}{4}$ "	247.4	315.0
$5 \frac{3}{8}$ "	15.07	19.18	5 $1$ "	77.15	98.23	9 $1$ "	253.9	323.2
$5 \frac{1}{2}$ "	15.86	20.20	5 $1 \frac{1}{8}$ "	78.95	100.5	9 $1 \frac{1}{8}$ "	260.4	331.6
$5 \frac{3}{4}$ "	16.69	21.25	5 $1 \frac{1}{4}$ "	80.77	102.8	10	267.0	340.0
$5 \frac{7}{8}$ "	17.53	22.33	5 $1 \frac{3}{8}$ "	82.62	105.2	10 $\frac{1}{8}$ "	280.6	357.2
$6$ "	18.40	23.43	5 $1 \frac{1}{2}$ "	84.49	107.6	10 $\frac{1}{2}$ "	294.4	374.9
$6 \frac{1}{8}$ "	19.29	24.56	5 $1 \frac{3}{4}$ "	86.38	110.0	10 $1$ "	308.6	392.9
$6 \frac{1}{4}$ "	20.20	25.00	5 $1 \frac{7}{8}$ "	88.29	112.4	11	323.1	411.4
$6 \frac{3}{8}$ "	21.12	26.90	5 $2$ "	90.22	114.9	11 $\frac{1}{8}$ "	337.9	430.3
$6 \frac{1}{2}$ "	22.07	28.10	5 $2 \frac{1}{8}$ "	92.17	117.4	11 $\frac{1}{4}$ "	353.1	449.6
$6 \frac{3}{4}$ "	23.04	29.34	5 $2 \frac{1}{4}$ "	94.14	119.9	11 $\frac{3}{8}$ "	368.6	469.4

\* Courtesy, COLUMBIA TUBE CO.

† These figures represent the theoretical weights of steel. Iron will run about 2 per cent lighter.

## BEND RADII AND BLANKING SIZES

The radius to which commonly used metals can be bent varies with the safety factor of the part and its structural significance. However, there are characteristic bend-radii suggestions, and these are shown in Table 39. Deviations from these suggestions should be made to accommodate design requirements; however, the physical properties of the metal to be bent should be kept in mind.

TABLE 39.—ALUMINUM AND ALUMINUM-ALLOY BEND RADIUS

Sheet thickness	24SO	24ST	28	38	52S
0.016	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
0.020	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
0.025	$\frac{1}{16}$	$\frac{3}{32}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
0.032	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{32}$	$\frac{1}{32}$	$\frac{1}{32}$
0.040	$\frac{3}{32}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
0.051	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
0.064	$\frac{1}{8}$	$\frac{3}{8}$	$\frac{1}{16}$	$\frac{1}{16}$	$\frac{1}{16}$
0.072	$\frac{5}{32}$	$\frac{7}{16}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$
0.081	$\frac{3}{16}$	$\frac{1}{2}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$
0.091	$\frac{3}{16}$	$\frac{9}{16}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{32}$
0.102	$\frac{7}{32}$	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$
0.125	$\frac{1}{4}$	$1\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$
0.156	$\frac{3}{8}$		$\frac{5}{32}$	$\frac{5}{32}$	$\frac{5}{32}$
0.188	$\frac{1}{2}$		$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$

Steel, including corrosion-resistant steel, Inconel metal, brass, bronze, and copper sheet, should be bent over a radius approximately equal to the thickness of the metal as follows:

TABLE 40.—STEEL, BRASS, BRONZE, ETC.

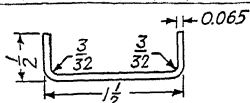
Sheet Thickness	Bend Radius
0.035 and less	$\frac{1}{32}$
0.038–0.065	$\frac{1}{16}$
0.072–0.095	$\frac{3}{32}$
0.102–0.125	$\frac{1}{8}$
0.156	$\frac{5}{32}$
0.188	$\frac{3}{16}$
0.250	$\frac{1}{4}$

Bend radii and their relation to blank sizes for sheet in computing the over-all size for shearing, etc., are important to the conservation of metal and the elimination of needless scrap. For this reason, Table 41 has been included to show a practical basis upon which these figures may be computed.



TABLE 41.—BLANKING AND SHEAR SIZES WITH BEND RADII

Radius gauge	$\frac{1}{32}$	$\frac{3}{64}$	$\frac{1}{16}$	$\frac{5}{64}$	$\frac{3}{32}$	$\frac{7}{64}$	$\frac{1}{8}$	$\frac{9}{64}$	$\frac{5}{32}$	$1\frac{1}{64}$	$\frac{3}{16}$	$1\frac{3}{64}$	$\frac{7}{32}$	$1\frac{5}{64}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$1\frac{1}{64}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
0.300																	499	512	525	549	579
0.284																466	479	492	506	529	559
0.259																422	435	449	462	476	499
0.238															390	396	410	423	437	450	473
0.220																		401	415	428	451
0.203																		381	394	408	431
0.180																		353	366	379	403
0.165																					
0.148																					
0.134																					
0.120																					
0.109																					
0.095																					
0.083																					
0.072																					
0.065																					
0.058																					
0.043																					
0.042																					
0.035																					
0.032																					
0.028																					
0.025																					
0.022																					
0.020																					
0.018																					



$$\frac{1}{2} + 1\frac{1}{2} + \frac{1}{2} = 2\frac{1}{2} = 2.5$$

From table, factor for 0.065

metal thickness and  $\frac{3}{32}$  radius

$$= 0.119$$

$$2.5 - 2(0.119) = 2.262 \text{ length}$$

## CHAPTER XII

### DESIGN PROCESS REQUIREMENTS FOR AIRCRAFT

Design process requirements are as closely related to the performance, maintenance, and service of the airplane as stress analysis, aerodynamics, and the other design requirements. In some instances, it might be said that these more physical requirements are directly contingent on the processes involved. In other instances, it can be stated that the process requirements are the life insurance of the design.

In previous chapters, the raw materials involved have been discussed more or less in detail. The characteristics both physical and chemical have been investigated. The matter of corrosion and inorganic and organic methods of protection have been offered. In this chapter, the necessity for employing the recommendations given is clearly shown by the requirements. The author does not mean to imply by the following discussion that the recommendations are unretractable, but those that are given are strictly in compliance with general design requirements.

**Drainage Requirements.**—Galvanic corrosion being of an electrolytic nature, a vehicle for the electrolyte, in the form of water, is ever present. The design should always present holes, channels, etc., that will drain pockets, recesses, etc., free from moisture. The method of such drainage should be designed with the attitude of the airplane at the time of drainage in mind. Where free drainage cannot be absolutely ensured, protection of parts on land planes should be guaranteed by extra coats of inorganic and organic surface coatings. Seaplanes and planes exposed to excessively wet conditions should be coated in suspicious areas with so-called “rust preventive compounds” such as Pal-al-Ketone.

**Seam Areas.**—These areas are easily described as those places where one or more pieces, commonly sheets or flat surfaces, contact each other and are subsequently mechanically joined. The contacting surfaces are generally referred to as “faying” surfaces. Design should qualify these surfaces in as close continuous contact with each other as possible. Buckling of such joints should be prevented by maintaining proper edge distances recommended for the method of securing such contacts. The faying surfaces of such contacts, even though “similar” in nature, should be well protected on each surface of contact.

**Gasoline Tanks.**—In general, gasoline tanks should be designed to eliminate the “pocketing” and trapping of moisture. This usually is

accomplished by retaining smooth bottoms, either rounded or pitched to a free corner or side, provided with a sump fitted with an antisplash device that prevents the collected moisture from returning to the tank proper. "Integral" fuel tanks—and by this is meant that or any area where the fuel is stored without the orthodox separate container and where the tank is part of the structure—should conform with the foregoing requirements as much as possible plus the sealing of all joints with Neoprene synthetic rubber inserts in all seam areas and under the heads or bucked ends of units. Steel bolts and nuts exposed to fluid should be metal-sprayed with hot aluminum metal. All seams should be further sealed with Zinc Chromate Paste, Type II. The interior of the tank should be protected with Zinc Chromate Primer. Primed interiors should be air-dried for a minimum of 2 weeks before being submitted to gasoline.

Tanks should further be furnished with a container containing potassium dichromate crystals or a combination of potassium dichromate and zinc chromate pigment.

*Dissimilar Metal Contacts.*—The contact among dissimilar metals is the designers' "bugaboo." By the term "dissimilar" is meant that chemical-composition dissimilarity should govern the case. 24ST aluminum alloy is dissimilar to 17ST. However, these compositions are not such glaring examples as steel and aluminum alloy or brass, bronze, copper, etc. Dissimilarity in contact means galvanic potentials to produce electrolysis. The contact among dissimilar metals should be avoided wherever possible, and where necessary the faying surfaces should be highly insulated by either inserts or Zinc Chromate Primer.

*Protection against Corrosive Exhaust Gases.*—The trapping of high-octane exhaust gases within the main structure through improper location of the exhaust stack should be avoided by designing and locating the exhausting system in the slipstream for subsequent dispersion of gases. Negative pressure areas should not be provided with holes or nests that might offer an entrance for such gases. The stack itself and the surrounding areas should be constructed of anticorrosive material or be well protected by anticorrosive organic finishing materials.

Characteristic protective-finish requirements for aircraft are given in the following. Strict adherence is not altogether required, but deviations should be well studied before adoption of a finish.

*Anodizing Aluminum Alloys.*—All aluminum-alloy parts or surfaces should be given anodic treatment. In general, the anodic treatment should be applied to parts in detail. However, disassembly for anodic treatment of a separate component should not be required when the following conditions are met: (1) when the assembly is situated in the structure so as not to come in direct contact with water or where the possibility is remote that water or moisture will enter or remain through lack of

free drainage; (2) when no dissimilar metals form a part of the assembly; (3) when the assembly is an integral unit of the structure not subject to breakdown or disassembly in service; (4) when waterproofing or insulating fabric compounds subject to deterioration in the electrolyte are not a part of the assembly; (5) when the final organic protective coating forms a continuous unbroken film. These recommendations should not be con-

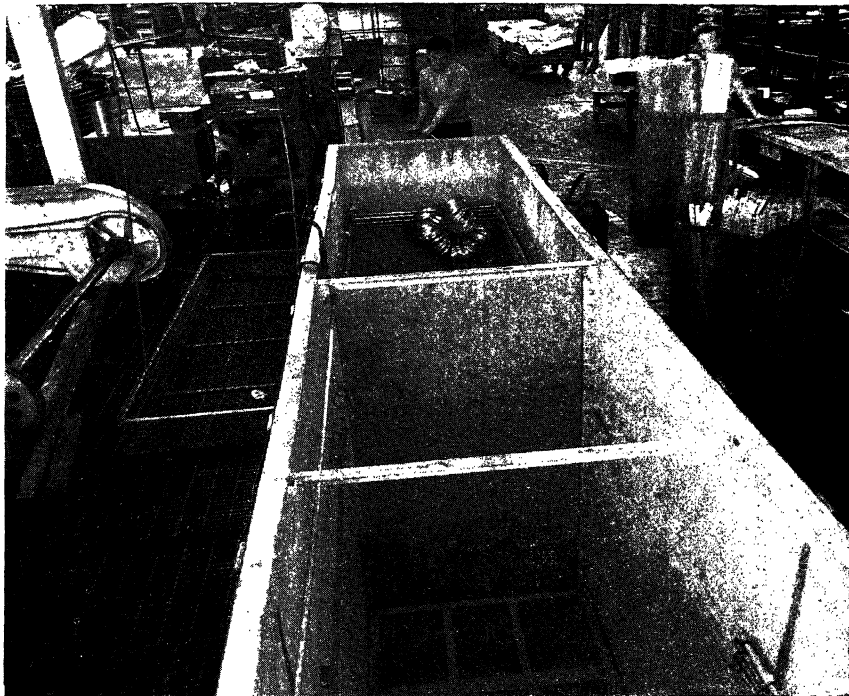


Fig. 13.—Solvent cleaning of metal parts by trichloroethylene vapor prior to finishing.

strued to permit the omission of a protective anodic film on faying surfaces where moisture may gain entry and be retained by capillary action. When advantage is taken of a waiver of the anodization of parts prior to assembly, the priming coat of Zinc Chromate Primer should be applied to the assembly immediately after anodizing.

**Anodizing Magnesium Alloys.**—Where magnesium alloy is used, parts or surfaces must be given anodic treatment or an equivalent treatment, as discussed in previous chapters.

**Electroplating.**—All steel parts, except as indicated, should be cadmium- or zinc-plated. All welding shall be done prior to the plating.

The plating should be uniform, possess good adhesion, and the quality should withstand a continuous 250-hr. 20 per cent salt-spray test without signs of rust appearing.

*Exceptions to Plating.*

1. When parts are manufactured of corrosion-resistant steel.

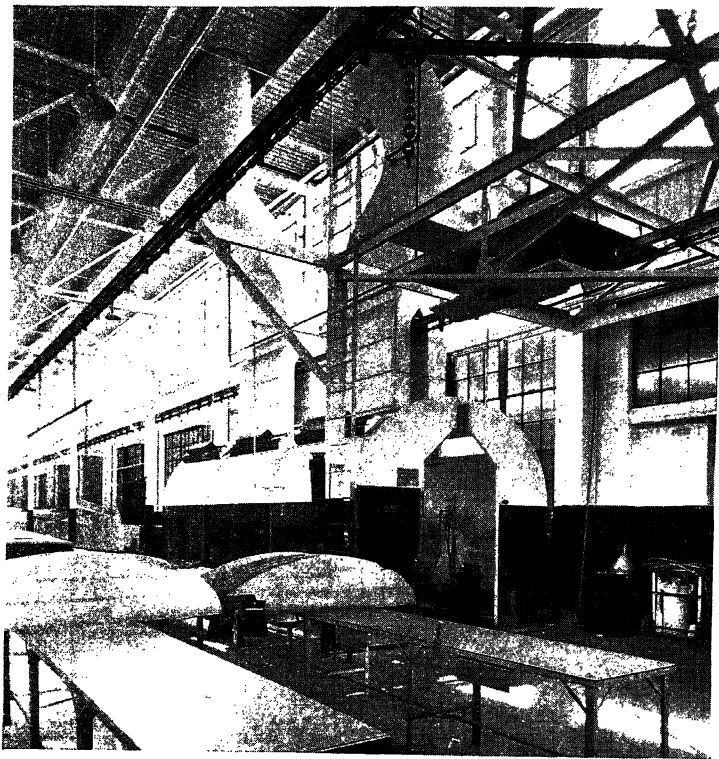


FIG. 14.—Spray-painting metal wing tips.

2. When parts are welded to unplated structures, such as cowlings supports.
3. When parts are welded structures such as fuselages and hollow parts and cannot be thoroughly cleaned to ensure removal of the plating solution.
4. When parts are cables or are fabricated from wire.
5. Those portions of members that act as bearings or journals. In general, springs should be electroplated.

**Metal Spraying.**—When used, metal spraying should be applied to sandblasting or pickled surfaces.

**Cleaning after Surface Treatment Prior to Paint Priming.**—In such cases, where there is an appreciable delay between anodizing or other inorganic surface treatment and application of priming coats, surfaces must be cleaned and dried to ensure against contamination resulting from the delay. If alkali solutions are used at this stage, the pH value should

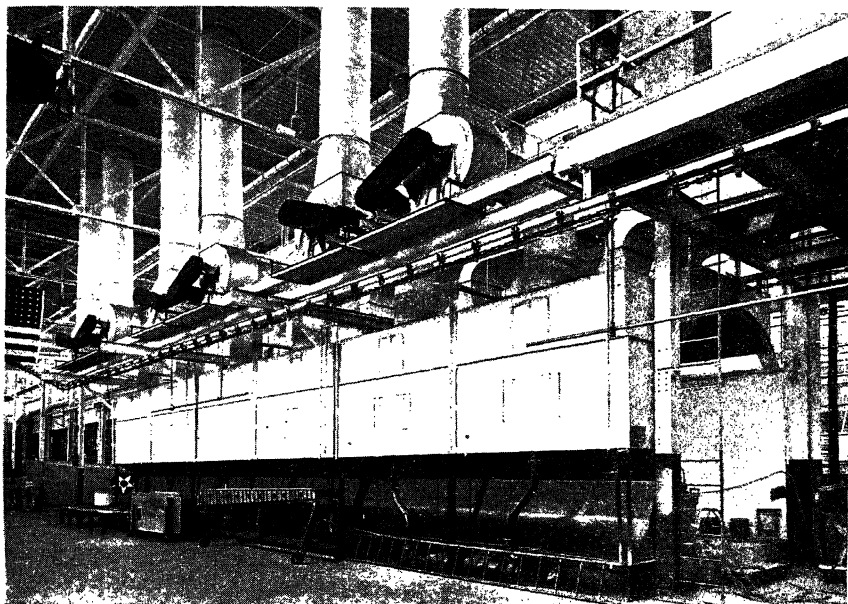


FIG. 15.—Large production paint spray booth.

not exceed 8.5. A quick method of cleaning superficial scum at this stage is by the use of naphtha.

**Cleaning Primed Surfaces after Fabrication Prior to Application of Finish Coats.**—After fabrication of subassemblies and assemblies of previously primed material, surfaces should be cleaned in such a way as to be degreased thoroughly, without leaving a residue of cleaning material and at the same time removing a minimum amount of the original primer. Hydrocarbon solvents may be used at this stage. Care must be exercised with joints so that cleaning materials are not admitted to crevices.

**Application of Organic Protective Coating Materials.** *Condition of Surfaces.*—All surfaces should be thoroughly cleaned and dry at the time

of application of any organic coating. They should not be handled by dirty or greasy hands after the final cleaning operation.

*Air and Weather Conditions.*—Organic coatings should not be applied under unfavorable air conditions. Wherever possible, coatings should be applied in air-conditioned rooms at approximately 75°F. Coatings should not be applied where directly exposed to high humidity. In unconditioned areas, consideration should be given to the wind direction.

*Preparation of Materials and Equipment.*—Materials should be prepared for use under clean conditions with clean equipment. Mixing should be done under controlled conditions by either weight or volume to ensure a high degree of uniformity of all materials prepared for use.

*Mixing of Aluminum Pigment.*—Aluminum paste is preferred to powder. Paste may be more readily incorporated in the vehicle and presents less hazard to the health of the operator. Pigment should be first wetted with a small amount of thinner so that the first operation provides a free-flowing paste that may then be gradually reduced by additional small amounts of thinner. Following this, the vehicle should be added.

*Dipping as an Application Method.*—The application by dipping to the greatest possible extent ensures more complete protection than any other method. This method is also economical from the standpoint of material and labor and should be extended in production processes as far as possible.

An example for the detail protective-finish requirements for a seagoing fighting plane is given in the following paragraphs.

#### FINISH-PROCESS REQUIREMENTS—FIGHTING SEAPLANE (WING ASSEMBLY ONLY)

##### DETAIL PREPROCESS REQUIREMENTS

These operations should be carried out on receipt of the stock and before storing.

#### I. Aluminum alloy—except spot-welded assemblies.

##### A. Alclad—heat-treated “ST.”

1. Alkaline-clean.

2. Anodize.

3. Dip or spray shop coat of Zinc Chromate Primer.

##### B. Alclad—not heat-treated—“SO” condition.

1. Handle in same way as in IA except that operations shall be carried out after heat treatment (see ID).

##### C. Non-Alclad parts (aluminum alloys).

1. Handle in same way as in IA and IB.

##### D. Omission of anodic coating.

1. Anodic coating should be omitted on the following:

a. Bonding clips, braid, and clamps.

b. Name plates.

c. Flexible conduit and end fittings.

- d.* Solid conduit.
  - e.* Conduit boxes.
  - f.* Switch boxes.
  - g.* Conduit fittings.
  - h.* Collars.
  - i.* Electrical disconnect plugs.
- E.* Extrusions for main structure.
  - 1. Alkaline-clean.
  - 2. Anodize.
  - 3. Dip or spray shop coat of Zinc Chromate Primer.

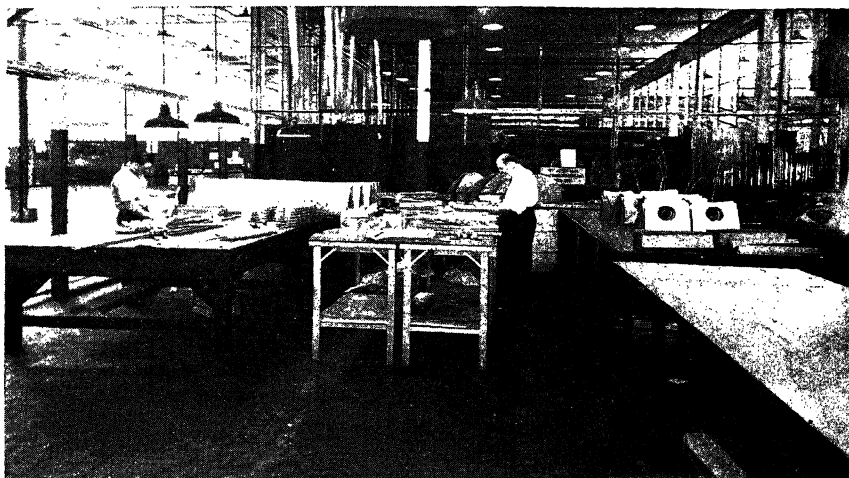


FIG. 16.—Detail process inspection prior to assembly.

- F.* Extrusions for secondary structure.
  - 1. Alkaline-clean.
  - 2. Anodize.

(No primer need be applied until assembly into a subassembly; the subassembly may then be primed by dipping.)
- G.* Extrusions for non-structural parts. Need not be preprocessed in detail but should be anodized and primed as an assembly.
- H.* Precleaning requirements. Parts, sheets, and forms heavily greased with mineral-oil-type compounds should be degreased with trichloroethylene before alkaline cleaning operations.

#### DETAIL PROCESS REQUIREMENTS

- I.* Anodic treatment.
  - A.* Should be applied to all aluminum alloys except those parts specifically exempted in *II*.
    - 1. Waterproofing and insulating fabric and compounds other than phenolic blocks used in elevator tabs and rivet spacers should not be submitted to the deteriorating effect of chromic acid baths.



- II. Steel, brass, bronze, and copper (unplated—not stainless).
  - A. Should be cleaned and cadmium-plated as follows:
    - 1. Shot blast when practical; otherwise:
      - a. Pickle.
      - b. Cadmium plate.
      - c. Finish.
  - B. All welding must be done prior to plating.
  - C. Forged, cast, and welded structures especially, as well as all other parts or materials classified as primary structure or important secondary structure should be magnetically inspected. Parts purchased under specifications should receive magnetic inspection on receipt.

#### DETAIL FINISHING-PROCESS REQUIREMENTS

- I. Cleaning of anodized, plated, and primed surfaces prior to subsequent finishing.
  - A. Anodized and plated surfaces. Anodized or plated surfaces intended for subsequent painting when contaminated from handling, etc., may be wiped clean prior to finishing lacquer thinner or naphtha. However, parts containing films of contamination so firmly attached as to resist such removal should be recleaned (alkaline).
  - B. Primed, shop-coated surfaces.
    - 1. Should be wiped free from superficial smudge and dirt with naphtha or toluol.
    - 2. Prime touch-up—all bare metal, cut off, sheared, machined ends and edges.
- II. Finish application conditions.
  - A. Anti-Blush.
    - 1. The use of Anti-Blush Retarders are permissible, providing that it occupies no more than 15 per cent of the thinner portion used to reduce the material to spraying consistency.
  - B. Special drying conditions.
    - 1. Should be observed for primer in the interior of fuel tanks as follows:
      - a. A primer on the interior of fuel tanks must have dried a minimum of 2 weeks prior to pressure testing (see the paragraph on Integral Fuel Tanks).
- III. Standard applicable finish schedules. The following finishing schedules should be considered standard and applicable:
  - A. Class I schedule is composed of:
    - 1. Two coats of primer.
    - 2. Two coats of finish to match adjacent surfaces.
  - B. Class II schedule is composed of:
    - 1. One coat of primer.
    - 2. Two coats of finish to match adjacent surfaces.
  - C. Class III schedule is composed of:
    - 1. One coat of primer.
    - 2. One coat of finish to match adjacent surfaces.
  - D. Class IV schedule is composed of:
    - 1. One coat of primer.
  - E. Class V schedule is composed of:
    - 1. The inorganic surface treatment only.

## IV. Rivets and boltheads.

## A. Should be finished as follows after driving:

1. Wipe clean with rag dampened with naphtha or toluol.
2. Prime.<sup>1</sup>
3. Finish.<sup>1</sup>

## B. Rivet holes should be touched up with Zinc Chromate Primer before inserting rivets.

## C. Exceptions to plating. The following parts should not be plated:

1. Parts made of corrosion-resistant steel.
2. Cable and parts fabricated from wire.
3. Parts welded to unplated structures.

## D. Bushings, other than flange and shoulder bushing, press fitted or push-fitted bushings or any member that has a surface acting as a bearing or journal should not be plated. Parts machined or reamed to close tolerance after plating need not have machined surfaces replaced. Apply Par-al-Ketone.

## E. Springs operating in oil or packed in grease or of corrosion-resistant steel shall not be plated.

All other parts should be finished as in part IIIA. *Shot blasting should not be used on springs.*

## V. Steel (corrosion-resistant).

## A. Should be

1. Pickled.
2. Passivated.
3. Polish or paint may be interchangeable here, depending on specific instructions of the cleaning.

## VI. Metal spraying (aluminum).

## A. Hot aluminum metal spray should be applied only to freshly shot-blasted or pickled surfaces, when metal spray is required.

## VII. Springs (unplated).

## A. Unplated springs should be installed coated with Par-al-Ketone.

## VIII. Specific-parts finishing (see Dissimilar Metal Contact).

- A. Exterior metal surfaces—Alclad should receive Class III finish schedule.
- B. Exterior metal surfaces—non-Alclad should receive Class II finishing schedule.
- C. The exterior color applied to all parts except as affected by insignia and marking should be M485 aircraft gray.
- D. Interior metal surfaces, wings, flaps, ailerons, and all parts contained therein unless otherwise specified should receive Class III finish schedule.
  1. The prime coat must have been applied in detail by preprocess or as otherwise arranged for on sprayed parts. Primary may be applied by dipping on subassemblies when spot-welded.
  2. The interior color applied to all parts unless otherwise specified should be yellow-green aluminized primer.
- E. Fuel tanks.
  1. Exterior should receive Class III finish schedule.
  2. Interior should receive Class IV finish schedule.
  3. Exposed boltheads and nuts should be hot aluminum metal sprayed prior to priming.

<sup>1</sup> It is imperative that rivet and boltheads receive the same finish schedule as adjacent surfaces.

- F. Non-structural tubing: open end non-ferrous (not air-speed); (see Tubing).
1. Interior should receive Class IV finish schedule.
  2. Exterior should receive Class III finish schedule to match adjacent surfaces.
- G. Tubing, closed, ferrous.
1. Interior should be flushed with Par-al-Ketone.
  2. Exterior should, in addition to plating, receive Class III finish schedule to match adjacent surfaces.
- H. Faying surfaces (not dissimilar metal).
1. Non-Alclad faying surfaces must receive two coats of primer on each surface, except where the assembly is an integral unit in the structure not subject to breakdown or disassembly in service (spot-welded, riveted, etc.). When this condition is the case, one prime coat on each faying surface is sufficient.
  2. Alclad faying surfaces should receive one coat of primer on each faying surface.
- I. Seam areas must be completely sealed by the subsequent application of the finishing coats. Brush application may be used to accomplish this if necessary.
1. Gasoline-tight seams must receive on the faying surfaces, the following coats of primer:
    - a. Non-Alclad—two coats.
    - b. Alclad—one coat. They should be sealed with:
      - (1) Neoprene tape—0.011 to 0.025 in. thick. Coated with Neoprene cement.
      - (2) Neoprene blocks should be installed in corners.
      - (3) Bolts in integral fuel tanks must be treated under the head and nut with seam compound to ensure liquid tightness.
  2. The liquid tightness of seam areas in fuel tanks should be proved by test in accordance with pressure-testing procedures.
- J. Insulation of dissimilar metals.
1. Ferrous and copper alloys should be protected by three coats of primer on each faying surface, in addition to a P.A.W. insert. For close tolerances, aluminum foil may be used.
  2. Close tolerances. When tolerances are too close for insulation by inserts, the faying surfaces may be insulated by means of primer only as follows: Dissimilar to:
    - a. Alclad—three coats of primer.
    - b. Aluminum alloy—four coats of primer.
    - c. Magnesium alloy—four coats of primer
    - d. Steel—five coats of primer.
    - e. Copper alloys—five coats.
  3. Small parts such as:
    - a. Riveted or elastic stop nuts.
    - b. Snap fasteners. Small parts other than those mentioned may be insulated by primer only where inserts are subject to wear, deterioration from heat, or other similar processes.
    - c. Dissimilar bonded connections should be insulated by foil, shims, washers, etc., of the proper material. No protective finish should be removed from the surfaces of any vital structure for bonding purposes where dissimilar contact is involved.

- K. Conduit (electrical—aluminum) all; junction boxes, fittings, control boxes should receive:
1. Interior.
    - a. Chrome pickle.
    - b. One coat of primer.
  2. Exterior.
    - a. Chrome pickle.
    - b. Two coats of primer.
    - c. Two coats of finish to match adjacent surfaces.
- L. Protection of bonding connections. Such connections should receive after installation:
1. One coat of primer.
  2. Two coats of finish to match adjacent surface.
  3. One coat of Par-al-Ketone.
- M. Control cables and chains. Control<sup>r</sup> cables must be protected with Par-al-Ketone prior to installation. Control chains must be coated with grease for lubrication.
- N. Wire controls (hard). The sheath and wire should be coated with Dixon's No. 5 Graphite grease prior to installing wire in sheath or casing.
- O. Standard parts.
1. Threads—ferrous parts should be coated with Par-al-Ketone prior to insulation.
  2. Threads—non-ferrous parts should be coated with Alcoa Threadlube prior to installation.
  3. Shanks or pins passing through dissimilar metals should be coated with Par-al-Ketone prior to installation.
  4. Aluminum washers must be used under all steel bolts, head and nut, when in contact with aluminum alloy.
  5. Rivets must be anodized by the Alumilite process (chromic acid acceptable).
- P. Integral fuel tanks. (See Detail Finishing-process Requirements VIII E.)
- Q. Tubing—structural—should be finished on the interior with the same finishing schedule applied to the exterior.
- R. Tubing—structural; sealed steel—must be sealed by welding. After all welding and brazing operations have taken place, the interior should be flushed with Par-al-Ketone. The member should then be closed with drive screws.
- S. Tubing—non-structural—should be finished as follows:
1. Aluminum alloy (2S-3S-52S), open system. Except flexible, should be finished inside and out with:
    - a. One coat of primer.
    - b. One coat of finish to match adjacent surfaces. This excludes air-speed tubing. Closed systems should not be painted on the interior. The exterior must be finished to match adjacent surfaces. Guide tubes or sheaths should be protected on the interior with Par-al-Ketone. Bomb-cable casing interiors must be coated with grease. Conduits carrying the casings are excluded.
- T. Color scheme.
1. Exterior should be Non-specular aircraft gray (camouflage requirement).
  2. Interior must be aluminized primer.

- U. Sub- and final-assembly touch up. All bare metal resulting from fabrication operations, other than rivet holes, should be touched up with aluminized primer in the sub or final assembly, depending on the practicability of the operation.

#### GENERAL NOTES

I. Use of potassium dichromate crystals.

- A. An aluminum container containing the following mixture should be located in each outboard wing tank.

1. Two parts potassium dichromate crystals. One part zinc chromate pigment.

#### FINISH-PROCESS REQUIREMENTS— LAND FIGHTING PLANE (WING ASSEMBLY ONLY)

By contrast, finish requirements for a land plane of the dive-bomber type are given below for comparison.

I. Cleaning prior to finishing.

- A. Alclad—heat-treated “ST.”

1. Alkaline clean.
2. Chromic acid dip.

a. Dip or spray shop coat of Zinc Chromate Primer. These operations should be carried out on receipt and before stocking. All identification marks must be replaced after shop coating.

- B. Alclad not heat-treated “SO” and non-Alclad parts (except extrusions, forgings, and castings) should be handled in the same way as Alclad, heat-treated “ST.”

- C. Aluminum-alloy extrusions, forgings, and castings.

1. Alkaline clean.
2. Chromic-acid dip.
3. Dip or spray shop coat of Zinc Chromate Primer.

- D. Gas-welded aluminum-alloy parts.

1. Passivate flux and clean.
2. Alkaline-clean.
3. Chromic-acid dip.
4. Zinc Chromate Primer.

- E. Steel (unplated and corrosion resistant), brass, bronze, and copper.

1. Steel (unplated).
  - a. Shop-blast where practical; otherwise:
  - b. Pickle.
  - c. Cadmium-plate.
  - d. No further finish required.
2. Steel (corrosion resistant).
  - a. Clean.
  - b. Zinc Chromate Primer—two coats.
3. Brass, bronze, and copper.
  - a. Clean.
  - b. Cadmium plate.

II. Omission of paint.

- A. Paint should not be applied to work surfaces, *i.e.*:

1. Screw threads.
2. Bearings.

3. Journals.
4. Oil holes.
5. Rubber or rubberlike surfaces. Such surfaces should also be free from grease, oil, and antirust compounds.
6. Nut-strip assemblies (except where specified)
7. Anchor nuts.
8. Elastic stop nuts
9. Safety wires.
10. Springs.
11. Rivets and cadmium-plated bolts.
12. Screws.

### III. Cables.

- A. Control cables should not be painted. They should, however, be treated with No-Oxid grease before assembly.

### IV. Lubrication of threads.

- A. Threads of aluminum-alloy parts demanding lubrication should be treated with Aloca Threadlube before assembly. Threads of steel should be lubricated with a lubricant meeting AN9516 specification (Army-Navy).
  1. Male threads of all metals should be treated as noted.
  2. All aluminum or aluminum-alloy bolts, machine screws, and threaded fittings in the electrical system should not be anodized and should be assembled only after coating the male threads with Aloca Threadlube.
  3. Bolts used in highly stressed fittings should not be painted but should be generously coated with rust-preventive compound material conforming to Army specification 2-84A.
  4. The threaded portion of steel or aluminum-alloy bolts assembled to elastic stop nuts should not be lubricated with thread compound, oil, or grease.

### V. Location of identification marks on aluminum-alloy skin sheets.

- A. The identification markings on the skin sheet should always in assembly be turned to the interior.

### VI. Insignia and markings; fabric application; camouflage scheme.

- A. Should be applied in accordance with individual drawing requirements.

### VII. Identification of electrical wiring.

- A. Electrical identification may be made by means of Minnesota Mining Co. clear-numbered cellulose tape.
- B. Cellulose tape should be protected by one coat of 3-158 clear lacquer (Army).

### VIII. Swaging. Procedure should be practiced as follows:

- A. The cable is cut to approximate length and one end inserted halfway into the swage fitting. A slight kink (45 deg.) is then made in the cable at the fitting so that when cable is pushed in the rest of the way, enough friction results from kink to prevent the fitting from falling off before swaging is actually started.
- B. S.A.E. 20 oil is applied to the exterior of the fitting and the swaging operation performed in a two-jawed cam-operated swaging machine, making approximately 3,600 blows per minute.
- C. The cable is then cut to the proper length and the opposite-end fitting applied.
- D. The cable is then proof-loaded, inspected, coiled, and treated with No-Oxid grease.

## DETAIL REQUIREMENTS

- I. Main spar.
  - A. Spar caps (after all machining).
    - 1. Alkaline-clean.
    - 2. Chromic dip.
    - 3. Spray or dip one coat of Zinc Chromate Primer.
  - B. Spar assembly.
    - 1. Drilled holes and counterbore areas for steel bolts must be touched up with Zinc Chromate Primer prior to assembly.
    - 2. Rivet holes need not be primed.
    - 3. Bolts used in attached forgings must be primed.
      - a. Magnetic inspected.
      - b. Protected with Zinc Chromate Paste Type II on faying surfaces of the heads.
    - 4. Faying surfaces of attaching forgings must be primed with Zinc Chromate Primer.
    - 5. Holes left bare in wing-attaching forgings should be protected with Par-al-Ketone.
    - 6. Machine countersunk areas for the dimpled skin should be touched up with Zinc Chromate Primer before assembly of the wing skin.
- II. Rear shear web assembly.
  - A. Sheet parts, forgings, other details.
    - 1. Should be shop-coated in detail before assembly with Zinc Chromate Primer.
  - B. All bolt holes and counterbores.
    - 1. Should be touched up with Zinc Chromate Primer before installation of bolts.
  - C. Bolts need not bear organic coating prior to installation.
- III. Inboard end rib.
  - A. All parts should be:
    - 1. Assembled from shop-coated stock.
    - 2. Countersunk and drilled for holes for bolts and rivets in all locations; the doubler plate should be touched up with Zinc Chromate Primer before installation.
- IV. Structure, detail assembly.
  - A. Stringers.
    - 1. Countersunk areas for dimpled skin should be touched up with Zinc Chromate Primer before assembly.
    - 2. Rivet holes need not be touched up.
    - 3. Scarfed ends only of stringers should be touched up with Zinc Chromate Primer.
  - B. Trimmed edges of sheet stock need not be touched up.
  - C. Assembly.
    - 1. Assembly does not need any further finish, inasmuch as it has been assembled from shop-coated stock. It is not necessary to touch up any bare metal, such as minor scratches, trimmed edges of sheet, (0.040 and under), and rivets.
  - D. Wing-tip light conduit bonding.
    - 1. The conduit should bear no finish.
    - 2. Bonding faying surfaces of clips and attachment must have the primer coating removed to establish bond. Bonding connections must be touched up with primer after bonding.

*E.* Aileron pulley, bearing plate.

1. Holes for pulley bolts should be touched up with primer before installation.

*F.* Chemical-tank brackets.

1. Aluminum-alloy parts—no further finish required.
2. Plated-steel parts—no further finish required; no dissimilar metal protection required.
3. Bolt holes.
  - a.* Channel skin and doublers must be touched up with primer.
  - b.* Skin should be covered with a small circular patch of pinked-edge fabric attached with 3-161 clear dope prior to application of camouflage coating.

*V.* Inspection doors—gauge identification.

- A.* Inspection doors must bear the gauge of the metal stamped on the interior side. Rubber stamping must be used.

*VI.* Elastic stop nuts.

- A.* Steel or aluminum-alloy stop nuts should bear one coat of Zinc Chromate Primer applied by brush at the bench; assembly on the faying surface only.

*VII.* Bushings and bearings—faying surfaces (steel).

- A.* Faying surfaces of bushings and bearing collars. When pressed, the outer surface must be coated with wet primer.
- B.* A bearing that is installed must have its outer surface coated with petrolatum.

*VIII.* Aileron differential parts.

*A.* Link assembly.

1. Normalize, Magnaflux, cadmium plate, and apply Par-al-Ketone.

*B.* End assembly; aileron control tube.

1. Magnaflux and cadmium plate.

*C.* Arm-aileron differential.

1. Forging, etched with chromic acid, one coat of zinc chromate—mask surface of bearing bore.

*D.* Pulley—aileron differential.

1. The molded-in center bushing is not cadmium-plated (AN210-2A Type).

*E.* Spacer—aileron pulley assembly.

1. Clean, etch, and prime. No further treatment to spacer and bearing.

*IX.* Trim tab mechanism.

*A.* Arm assembly—tab rocker.

1. Clean, etch, and prime.
2. Bearings are spun in with petrolatum.

*B.* Bushing faying surfaces.

1. Brush one coat Zinc Chromate Primer; install by pressing wet.

*C.* End assembly.

1. Bushing.
  - a.* Install with wet primer by pressing.

*D.* Tube.

1. Alkaline-clean.
2. Chromic acid etch.
3. Prime inside and out.

*E.* Nut.

1. Anodize—no further finish required.



- F. Bracket assembly.
  - 1. Treat same as end assembly.
- G. Drum—trim tab control.
  - 1. Alkaline-clean.
  - 2. Chromic-acid dip.
  - 3. Spray one coat of Zinc Chromate Primer.
- H. Nut.
  - 1. Install with wet primer by pressing.
- X. Aileron fabrication.
  - A. Metal framework.
    - 1. Hinge brackets.
      - a. Alkaline-clean.
      - b. Chromic-acid dip.
      - c. Prime one coat of Zinc Chromate Primer.
    - 2. Faying surfaces.
      - a. Must bear one coat of Zinc Chromate Primer on each surface before assembly.
    - 3. Counterweights (lead).
      - a. Prime.
      - b. Par-al-Ketone surfaces in contact with aluminum alloy.
      - c. Prime nut strips, and install bolts and nuts with Par-al-Ketone.

It is hoped by the foregoing information the reader has established definite ideas as to the comparative protective requirements of different types of planes.

## CHAPTER XIII

### PRODUCTION USE OF ZINC CHROMATE PRIMER

Zinc chromate as an inhibitor against corrosion gained some prominence in World War I. Henry A. Gardner, of the National Paint and Varnish Institute, pioneered with considerable research on this pigment in vehicles of linseed oil, long oil, spar varnishes, etc., utilizing the product as a priming coat for ferrous metals, replacing red lead. However, it was not until approximately 1930 that zinc chromate received the attention it deserved.

With the advent of quicker drying vehicles and the complex phenolic and alkyd resins, more intense research was devoted to the incorporation of these materials with a later and purer zinc chromate.

It can safely be said that the first production use of Zinc Chromate Primer on transportation systems was made by the Ford Motor Co. prior to 1929. J. L. McCloud, of that company, in a paper read before the American Chemical Society and later published in *Industrial Engineering Chemistry*, Vol. 23, page 334, December, 1931, proposed the adoption of such a primer for non-ferrous metals. This primer was formulated and manufactured by Ford for their own use and subsequently submitted to the Materiel Division, Army Air Corps, at Wright Field for test and approval.

Some time in 1934, interest in such a primer was shown by the Naval Aircraft Factory. Lieutenant Commander C. F. Cotton, USN, attached to the materials laboratory at the naval aircraft factory, and H. Acker, now with the W. P. Fuller Co., then stationed at the Naval Aircraft Factory, instituted considerable tests and research that resulted in the issuance of N.A.F. specification P-27a. M. R. Whitmore, U. S. Army, materials division, instituted tests of other makes of materials based on the successful Ford primer. The author, in collaboration with H. Acker, developed and offered for sale, on a government contract, the first production Zinc Chromate Primer.

This material has been changed from time to time. Specifications have been rewritten until today we have the universal use of zinc chromate primers P-27-b-2 (Navy) and 14080 Zinc Chromate Primer (Army).

The production use of Zinc Chromate Primer varies from orthodox primers in many ways.

**Reduction for Use.**—Although orthodox primers rarely require more than equal parts of thinning agent, zinc chromate requires 3 parts thinner to 1 part primer. This might seem a considerable amount of thinner to use. However, the viscosity and solids of the primer are built to withstand this reduction.

The peculiarities of zinc chromate primers were dealt with to some extent in other parts of this book. They will not be repeated here. However, composition and handling requirements are of interest, and these are explained.

In Table 42 will be found the composition of zinc chromate primers to meet both Army and Navy requirements.

TABLE 42

Army	Per cent	Navy	Per cent
Product, non-volatile.....	56	Product, non-volatile.....	60
Volatile.....	44	Volatile.....	40
Non-volatile, vehicle.....	30	Non-volatile, vehicle.....	44-46
Pigment.....	30	Pigment.....	56-54
Vehicle, resins and oils.....	70	Volatile, hydrocarbon solvents....	100
Pigment, zinc chromate.....	85	Vehicle, resins and oils.....	100
Extender.....	15	Pigment, zinc chromate primer....	85
		Magnesium silicate extender....	15

It will be noticed in the preceding table that the two primers compare very closely.

In the first chapters, the peculiarities of the film deposited by reduced Zinc Chromate Primer have been discussed. It is well, however, to discuss them slightly further in order to obtain a clear picture by correlation.

Army or Navy zinc chromate primers work best for a spray application when reduced  $2\frac{1}{2}$  to 3 parts toluol to one part primer. A reduction of equal parts of primer and toluol is recommended for dip application. As previously discussed, one spray cross coat sprayed at 50 lb. of pressure with the reduction recommended will deposit sufficient primer film for all ordinary cases. A tendency to overload with primer should definitely be avoided.

Zinc chromate primers have a tendency to become extremely hard on aging, and it is suggested that primed films be aged no longer than 72 hr. before applying subsequent top coats. Over-aged primer films decrease the adhesion between the primer and top coats. Over-aged films should always be cleanly stripped or softened with a mist coat of Xylol.

Characteristic shop instructions on the use of zinc chromate primers should conform basically with the following:

1. Surface conditions.
  - a. All surfaces to be primed must be clean, dry, and free from dirt, grease, and other film matters.
2. Application by spray.
  - a. The primer should be reduced in accordance with the recommendations given.
  - b. The primer should be constantly agitated in the reduced condition.
  - c. Primer aged in the reduced and liquid state and held in spraying and dipping equipment for longer than 72 hr. should be examined closely for separating and breaking characteristics.
  - d. 0.001 in. thickness of primer should be the minimum spray coat allowed.
3. Application by dipping or flow coating.
  - a. Reduce for application in accordance with instructions.
  - b. Agitation continuously during use is absolutely essential.
  - c. Additional thinner must be added from time to time to compensate the evaporation of the solvent. A viscosity of consistency can be assured by the use of proper hydrometer.
4. Atmospheric conditions.
  - a. Application of primer should be conditioned in an atmosphere of relative humidity not over 70 per cent and a room temperature of 70 to 80°F.
5. Drying time.
  - a. Zinc Chromate Primer dried under proper atmospheric conditions dries hard enough to handle in 5 to 10 min. Lacquer or primer top coats can be applied after 3 hr.

## CHAPTER XIV

### CLEANING AND PREPARATION OF AIRCRAFT METAL PARTS PRIOR TO APPLICATION OF PROTECTIVE COATINGS

The necessity for a procedure and routine for the cleaning of metal parts prior to the application of subsequent protective coatings is well known. The fact that the subsequent top coatings and their ability to protect are very dependent on their attachment brings about a need for definite requirements governing the preparation of surfaces for attachment.

Six major and important metals are discussed in the following paragraphs, with definite instructions for cleaning for the application of top coatings; although later methods may supersede such instructions, basic principles will remain unaltered. It can be safely said that the instructions given adhere closely to the requirements by the procuring agencies for both military and naval planes.

Two important factors are involved in the chemical treatment of metal surfaces:

1. When treatments for cleaning and preparation of the surface involve the use of a material having a specific acid or alkaline nature, such treatments must always be followed by a hot-water rinse to remove the acid or alkali and to promote a neutral surface.

2. Initial protective coatings, whether organic or inorganic, should be applied as soon after the cleaning operation as possible. Particular attention should be given to sandblasted parts, inasmuch as sandblasting breaks the surface to promote a rough "tooth" necessary for the adhesion of subsequent coatings and by so doing brings about corrosion at a faster rate than would ordinarily occur.

#### STEEL--NOT CORROSION-RESISTANT

There are five optional methods for the preparation of steel surfaces. The first and basic, when practical, is sandblasting or shot blasting. Sandblasting and shot blasting are used mostly as quick, practical, dependable methods for the removal of rust, heat-treated scale, superficial scum, and dirt. The part subjected to sandblasting or shot blasting should be studied for its ability to withstand the loss of material involved in the operation.

Electrocleaning by the use of an alkaline cleaner in a tank possessing a cathode and an anode (the tank is usually used as the cathode, and the

work rod is used as the anode) operated at 4- to 6-volt potential, with the bath being maintained at approximately 180°F., typifies the ordinary setup for electrocleaning. This method is often employed for grease, dirt, and scum. It is not, however, recommended for the use of rust or heat-treated scale. The use of a wire brush or steel wool is acceptable for localized areas but is very impractical in large areas.

Organic cleaning agencies or solvents such as benzole, carbon tetrachloride, lacquer thinner, naphthas, etc., may be used when practical. This type of cleaning, however, is reserved for use in removing only superficial dirt and contamination from the machine or smooth surfaces.

Pickling of steel prior to plating aligns itself as a method for sand-blasting. There are two methods of pickling:

1. *Cold method* for mild scale and rust involve the use of the electrocleaning operation mentioned above and then submitting the steel to a 10 per cent solution of sulphuric acid (commercial 66°Bé.) operated at 25°C. The length of immersion is dependent on the degree of contamination. After cleaning, parts should be rinsed well in hot water until neutral.

2. *Hot method* for heavy scale and rust. It is much the same as the cold method insofar as the employment of the electrocleaning operation is concerned. However, the pickling solution is replaced by the use of 40 per cent commercial hydrochloric acid, which is operated as a bath at 140°F.

When the pickling of steel springs is involved, the springs should be neutralized and dried and baked for 1 hr. at 300°F. It will be found that the temperature may vary for certain parts; however, in definition, the upper limit might be explained by recommending that the steel wire whose carbon content exceeds 0.40 and whose final diameter or thickness is less than  $\frac{1}{4}$  in. should be baked at 375°F. for 3 hr. after the plating operation. Plated springs should not be flexed prior to baking.

#### CLEANUP OPERATIONS FOR CADMIUM PLATING

The cadmium plating of steel, brass, and bronze parts is a general requirement applicable to both military and naval planes. Prior to the plating operation, the work should be submitted for one of the five methods of cleaning mentioned above. All plating operations should be carried on after all welding and brazing operations have been completed. The application of cadmium to threaded parts should be done without undercutting of the threads prior to plating, unless drawing requirements issued for the part specify otherwise.

The cadmium plating requires no preliminary coats such as those used under chromium plating (such as copper and nickel).

The ordinary thickness of cadmium plate acceptable on military and naval articles is approximately 0.005 in. This determination is made by

considering the amount deposited on the smooth surfaces only. The usual test for cadmium-plate thickness is by the drop-test methods, with the use of a solution as follows:

CP ammonium nitrate.....	110 g.
Hydrochloric acid (specific gravity 1.18).....	10 cc.
Distilled water.....	To equal 1 l.

For further details on the cadmium-plating operation itself, see Chap. XXII.

All cadmium-plated parts intended for subsequent top coating should be passivated by immersion prior to finishing. This passivating operation should consist of immersion in a 4 to 6 per cent solution of flake chromic acid.

### CORROSION-RESISTANT STEEL

The cleaning of corrosion-resistant steel and the subsequent passivation of its surface may be done by immersing the part in the following solution at 25°C.:

	Per Cent by Volume
Nitric acid (42°Bé).....	20
Hydrofluoric acid (48%).....	10
Water.....	70

Follow the immersion by rinsing well in hot clean water. After rinsing, submit the part to a further immersion in a 20 per cent (by volume) solution of nitric acid for 30 min. Remove, and rinse well with hot water.

All articles treated by this procedure should be checked for acidity with phenol phthalein.

### BRASS AND BRONZE PARTS

The passivation of brass and bronze surfaces following brazing and soldering operations as well as removal of scale due to brazing and soldering may be accomplished by first cleaning parts by electrolytic cleaner. This should then be followed by dipping in the solution outlined below:

Sulphuric acid (66°Bé.).....	1 fluid oz.
Sodium bichromate.....	1 avdp. oz.
Water.....	1 gal.

Following this immersion, parts should be rinsed well with hot water. If the parts are to be left without any protective coating or merely with the top coat with clear lacquer, they may be "bright-dipped."

"Bright dipping" is usually applied to copper and copper-alloy surfaces, particularly tubing, following the passivating operation outlined above. This operation consists of dipping the parts in

Sulphuric acid (66°Bé.)	56 %
Nitric acid	16.7 %
Hydrochloric acid (24°Bé.)	0.1 %
Water	26.5 %

This solution should be operated below 95°F., and all parts "bright-dipped" should be rinsed well in hot water, following the dipping operation.

### NEUTRALIZING OF SOLDERED PARTS

Because acid-core solder is used in the soft soldering of various parts, the need for neutralizing the acidic surface is highly important. All parts so soldered should be passivated and neutralized by the application of the solution below:

Soda ash	2.0 oz. avdp.
Water	1.0 gal. (volume)

Dissolve the soda ash in hot water, but use only when cool. Apply the solution either by immersion or swabbing, followed by a clear hot-water rinse.

### ALUMINUM AND ALUMINUM ALLOYS

There are two approved methods for the cleaning of aluminum and aluminum-alloy surfaces for degreasing and removal of scum and dirt imparted to the surface by rough handling: initial alkaline degreasing and solvent degreasing.

Initial alkaline degreasing consists of immersing parts or surfaces in the following solution:

Alkaline cleaner (Navy M354 type)	8 oz. avdp.
Water	1 gal. (volume)

Dissolve the cleaner in hot water, and operate the solution between 180 and 212°F.

Parts cleaned as above should be immersed until the surface shows by washing a "non-break water film" indicating cleanliness. Immersion in the alkaline cleaner should be followed by rinsing in hot water.

Solvent degreasing may be done either manually or by vapor. Manual degreasing consists of the application of a solvent such as a hydrocarbon or ester to the affected part by brushing or wiping. Vapor degreasing is carried out by placing the parts in a specially constructed cabinet for proper solvent recover and vaporizing trichloroethylene throughout the cabinet.



When neutralizing welded aluminum-alloy parts for flux passivation, the following solution is recommended. In the case of gas tanks or other closed members, the solution should be agitated freely within the closure to ensure contact with all affected areas.

Sulphuric acid (66°Bé.)	10 %
Water	90 %

The preceding solution may be operated cold (room temperature). Free rinsing of the part in clean hot water should follow the passivation operation.

### MAGNESIUM ALLOY

The preparation of magnesium-alloy surfaces for top coating involves a somewhat more lengthy and technical method than that employed for aluminum and aluminum alloys. The cleaning of magnesium sheet and forgings may be accomplished in the same fashion as the method recommended for aluminum and aluminum alloys, *viz.*, the use of the Navy M354-type alkaline cleaner and solution. The cleaning of magnesium castings should be done electrolytically.

Heavy castings of magnesium and magnesium alloy should be dichromated following the cleaning operation as follows: Immerse the parts in a solution of

52% hydrofluoric acid	2 gal.
Water	1 gal.

This should be followed by a thorough rinse in clean hot water. After the rinsing operation, immerse the castings for 45 min. in the following solution at 212°F.:

Sodium dichromate	0.75 lb.
Water	1 gal.

Dissolve the dichromate in hot water. After immersion in the dichromate solution, the castings should be rinsed thoroughly in hot water and completely dried with air or low heat.

Light castings should be chromium-pickled by immersing the parts in the following solution maintained at room temperature:

Sodium dichromate	1.5 lb.
Nitric acid (42°Bé.)	8 oz. (volume)
Water	116 oz. (volume)

Immerse the parts in the bath for approximately 5 to 8 sec., and upon withdrawing, hold over the bath for another 3 to 5 sec. Follow this with a thorough rinse in hot water, and then dry well with air or low heat.

Methods for the treatment of magnesium have been given in Chap. IV. For variation of the instructions given above, see this reference.

#### **HOT CHROMIC ACID ETCH FOR ALUMINUM AND ALUMINUM ALLOYS**

Recently chromic acid etching has been substituted for anodizing for aluminum and aluminum alloys on planes manufactured for the Army Air Corps. The chromic acid etched surface, however, is in all cases followed by subsequent organic protective coatings.

The chromic acid etch of aluminum and aluminum-alloy surfaces may be done by dipping parts in a hot 4 to 6 per cent chromic acid solution maintained at 40°F. for from 8 to 15 min., depending on the surface. The surfaces should not be exposed to the chromic acid solution, however, until they have been alkaline-cleaned, as recommended under the cleaning method given for anodized films. After immersion in the hot chromic acid solution, parts should be followed by a thorough hot-water rinse and dried immediately. Parts etched with chromic acid should be handled at all times with clean canvas gloves to prevent contamination and should be protected by their subsequent top coat as quickly as is practical.

## CHAPTER XV

### HEAT TREATMENT OF AIRCRAFT STEELS

Although many steels are found in the aircraft industries, the common steels used and required amount to approximately 24 to 25 in number. The detail heat treatment for these will be found in the following pages.

Structural steels used in production should be normalized before hardening operations are made. This normalizing operation allows for proper degree of hardness for initial machining operations. Tool steels, however, are not normalized but are purchased in the spheroidized annealed condition.

Routine checks on all steel stock should be made periodically. This investigation should include

1. Chemical analysis.
2. Acid etching of representative cross sections for investigations as to structure.
3. Microscopic examination for inclusion.
4. Determination of grain size and direction.

A representative sample of the steel stock should be submitted to the heat treatment prescribed for the particular type of steel involved and the results compared with the specification requirements.

A definition of heat-treatment terms might be considered as follows:

#### HEAT-TREATMENT FURNACES

Heat-treatment furnaces are usually any furnaces of a suitable type and design capable of maintaining uniform temperatures within plus or minus 10°F. of the prescribed temperatures. They should be equipped with proper controls of the recording type and preferably should be electrically heated. An example of heat-treatment furnace ordinarily employed for the heat treatment of steel may be well described by referring to the Lindbergh furnace now in actual operation in one of the large aircraft plants. This particular type of furnace is of the hydrolyzing type and is quite simple and practical for treating a wide variety of steels without scaling, carburizing, or decarburizing the production. The main part of the atmosphere employed is produced by burning charcoal with insufficient air for complete combustion in a gas generator.

The gas from the charcoal generator is practically neutral in itself, but to prevent positively decarburization of the work, it is necessary

to supplement this gas with a small amount of ammonia and benzol. This is true, however, only on high-speed steel.

All gases for the atmosphere are introduced through three inlets in the bottom of the furnace. The benzol and ammonia are mixed with the charcoal gas just before it enters the furnace. Excess atmosphere is vented from the furnace through two outlets near the top of the furnace that are connected to a burner above the furnace. Combustion is maintained at this burner by means of a Pyrofax gas pilot (city gas may be used).

The furnace is of gas-tight and heavily insulated construction. Heat is applied by means of nickel-chromium electric elements located on the side walls of the furnace. The tubular shape of the elements provides maximum mechanical strength and also the greatest possible amount of heat-dissipating surface.

The elements are divided into three separate zones of control. Temperature regulation of each zone is affected by means of a standard Leeds & Northrup indicating and controlling potentiometer-type pyrometer and a Type AA Lindbergh control, operating a magnetic contactor that interrupts the power to the elements. A permanent record of the temperatures maintained in each zone is made by a standard Leeds & Northrup three-point recording potentiometer-type pyrometer.

**The Generator.**—The generator consists of an insulated steel cylinder with a removable top cover, a hopper in the upper portion, a refractory combustion chamber below this, and an ashpit in the bottom. A shaker-type grate is provided for removal of ash from the combustion zone. For normal operation, air is introduced to the charcoal through the ashpit; gas is formed in the combustion zone and bled off to the furnace through the top of the generator.

Ordinarily, the generator will hold fire overnight, so that it will not be necessary to light it every day. If the fire has gone out or if the generator is being started for the first time, the procedure outlined below should be followed.

1. Be sure that the furnace temperature is at least 1300°F. This precaution is necessary to eliminate the possibility of explosion.

2. Fill the generator to the top with No. 3 hardwood retort charcoal, approximately 3.5 bags.

3. Poke the charcoal down with a long steel poker bar sharpened on the lower end. Refill the generator if necessary.

4. Replace the cover on the generator, and light the Pyrofax gas pilot on the furnace-vent bleeder.

5. Open the ashpit door, and insert a wad of lighted paper or oiled

6. Start the blower, and close the ashpit door simultaneously.

In filling and poking down a hot generator, the operator should never under any circumstances put his face over the cover opening. The reason for this precaution is that the hopper normally fills with gas, and when the cover is opened, the gas mixes with air, giving a combustible mixture that may ignite with a mild explosion. This is perfectly normal part of the operation of the equipment, and no harm will be done if the operator keeps his face from the opening.

**Benzol and Ammonia.**—The function of these constituents is to form methane and hydrogen in the furnace and prevent decarburization of tool steels. The benzol itself cracks in the presence of heat to form methane and free carbon. Then the carbon thus released combines with hydrogen from dissociated ammonia to form additional methane. There is hydrogen left over from these reactions but no free carbon, since this would cause sooting and be undesirable.

Care should be exercised in handling benzol, for it is highly inflammable, and spillage on filling should be avoided. Excessive heat should be kept away from the benzol tank and pump. Similar care should be used in the handling of ammonia. A pressure-relief safety seal has been provided near the benzol- and ammonia-mixing tube to provide release of pressure, should the lines be stopped up for any reason. The safety seal consists simply of a tube extending down in 8 or 10 in. of oil, which is sufficient to hold normal operation pressure in the line. Should the oil be blown out of the seal, it is necessary only to unscrew the lower part and fill it with quenching oil up to the level screw in order to put it back in service.

**Control of the Furnace Atmosphere.**—Start with between 20 to 30 drops per minute and 6 cu. ft. of ammonia. A great deal of careful experimentation over a period of time has shown that controlling the hydrolyzing atmosphere is not a matter of hairline precision. Common practice is to determine the approximate benzol, ammonia, and charcoal flows that are satisfactory and then to use these settings for work to be run, regardless of the type of steel.

**Cooling Furnace.**—Provisions for speeding the cooling of the furnace for lower temperature operation have been made by means of purging with air. A tee has been placed in the generator gas line leading to the inlets in the bottom of the furnace, thus making it possible to shut off the hydrolyzing gas and run the purging air through the same pipe line. Shutoff cocks are installed in front of the tee on both the gas and air lines. Be sure that both cocks are not open at the same time, for an inflammable mixture will result.

To purge the furnace, the procedure outlined below should be followed:

1. Shut off the benzol unit and ammonia tank.
2. Close the shutoff cock in the charcoal-generator line.

3. Stop the generator blower.

4. Open the shutoff cock in the air line, and allow the furnace to cool to the desired temperature.

**Pyrometers.**—Pyrometers should be automatic and recording, as explained. The thermocouples used in conjunction with the pyrometers should be installed in protection tubes.

**Routine Check of Pyrometer Equipment.**—Pyrometer equipment should be checked for accuracy at regular established intervals by placing a calibrated couple alongside the working cup and comparing temperature readings by a recorder whose action has been standardized. This check test should be made under normal production conditions while the furnace has a complete charge and is operating at the normal temperature recommended for the charge.

**Quench Tanks.**—Quench tanks are used for holding the quenching minimum necessary to chill the furnace charge quickly. They are usually made of steel of the required size and provide for a circulatory system that will promote the circulation and cooling of the quenching minimum. The tank should be capable of operating so that the main body of the quenching minimum will not increase in temperature from the submission of the charge more than 20°F.

## MECHANICS OF HEAT TREATMENT AND DEFINITIONS

The primary step in the heat treatment of all steel is the initial heating to a point within or above the transformation range in order to put the iron in a gamma condition. This brings about the solution of carbon and other elements that form a solid solution state or austenite.

The rate of heating to the points mentioned is not quite so important as the ultimate temperature desired. However, the rate of heating must be commensurate with the load of the furnace and the thickness of metal involved.

The ultimate temperature or maximum temperature is dependent a great deal upon the chemical composition and the maximum permissible austenite grain size. This, of course, will be dependent on whether the grain size has been specified. The higher the temperature within certain limits, the greater the solubility of the carbide or ferite phases, which, in turn, influence the rate at which they are dissolved in the austenite. The higher the temperature, of course, the larger the austenitic size.

The soaking time or time necessary to hold the furnace charge at maximum temperature is decided on the furnace charge and the amount of carbide and alloying elements desired in solution. A general rule can be established on the basis that the soaking period should be long enough to equalize conduction of the heat throughout the furnace charge and to arrive at composition changes desired. This, of course, in all

TABLE 43.—CARBON STEELS\*

S.A.E. number	Carbon range	Manganese range	Phosphorus, max.	Sulphur, max.
1010	0.05-0.15	0.30-0.60	0.045	0.055
1015	0.10-0.20	0.30-0.60	0.045	0.055
X1015	0.10-0.20	0.70-1.00	0.045	0.055
1020	0.15-0.25	0.30-0.60	0.045	0.055
X1020	0.15-0.25	0.70-1.00	0.045	0.055
1025	0.20-0.30	0.30-0.60	0.045	0.055
X1025	0.20-0.30	0.70-1.00	0.045	0.055
1030	0.25-0.35	0.60-0.90	0.045	0.055
1035	0.30-0.40	0.60-0.90	0.045	0.055
1040	0.35-0.45	0.60-0.90	0.045	0.055
X1040	0.35-0.45	0.40-0.70	0.045	0.055
1045	0.40-0.50	0.60-0.90	0.045	0.055
X1045	0.40-0.50	0.40-0.70	0.045	0.055
1050	0.45-0.55	0.60-0.90	0.045	0.055
X1050	0.45-0.55	0.40-0.70	0.045	0.055
1055	0.50-0.60	0.60-0.90	0.040	0.055
X1055	0.50-0.60	0.90-1.20	0.040	0.055
1060	0.55-0.70	0.60-0.90	0.040	0.055
1065	0.60-0.75	0.60-0.90	0.040	0.055
X1065	0.60-0.75	0.90-1.20	0.040	0.055
1070	0.65-0.80	0.60-0.90	0.040	0.055
1075	0.70-0.85	0.60-0.90	0.040	0.055
1080	0.75-0.90	0.60-0.90	0.040	0.055
1085	0.80-0.95	0.60-0.90	0.040	0.055
1090	0.85-1.00	0.60-0.90	0.040	0.055
1095	0.90-1.05	0.25-0.50	0.040	0.055

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 44.—FREE-CUTTING STEELS\*

S.A.E. number	Carbon range	Manganese range	Phosphorus range	Sulphur, max.
1112	0.08-0.16	0.60-0.90	0.90-0.13	0.10 -0.20
X1112	0.08-0.16	0.60-0.90	0.90-0.13	0.20 -0.30
1115	0.10-0.20	0.70-1.00	0.045 max.	0.075-0.15
1120	0.15-0.25	0.60-0.90	0.045 max.	0.075-0.15
X1314	0.10-0.20	1.00-1.30	0.045 max.	0.075-0.15
X1315	0.10-0.20	1.30-0.60	0.045 max.	0.075-0.15
X1330	0.25-0.35	1.35-1.65	0.045 max.	0.075-0.15
X1335	0.30-0.40	1.35-1.65	0.045 max.	0.075-0.15
X1340	0.35-0.45	1.35-1.65	0.045 max.	0.075-0.15

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

cases, should be balanced by correlating the desirable time of soaking period against an overgrowth of austenitic grain size.

The required initial furnace temperature for hardening, normalizing, and annealing is generally acceptable at not less than 500°F. below the ultimate temperature for the work involved. It is further generally required that the temperature be arrived at gradually. For tempering, the furnace should not be hotter than 1000°F.

TABLE 45.—MANGANESE STEELS\*

S.A.E. number	Carbon range	Manganese range	Phosphorus, max.	Sulphur, max.
T1330	0.25-0.35	1.60-1.90	0.040	0.050
T1335	0.30-0.40	1.60-1.90	0.040	0.050
T1340	0.35-0.45	1.60-1.90	0.040	0.050
T1345	0.40-0.50	1.60-1.90	0.040	0.050
T1350	0.45-0.55	1.60-1.90	0.040	0.050

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 46.—NICKEL STEELS\*

S.A.E. number	Carbon range	Manganese range	Nickel
2015	0.10-0.20	0.30-0.60	0.40-0.60
2115	0.10-0.20	0.30-0.60	1.25-1.75
2315	0.10-0.20	0.30-0.60	3.25-3.75
2320	0.15-0.25	0.30-0.60	3.25-3.75
2330	0.25-0.35	0.50-0.80	3.25-3.75
2335	0.30-0.40	0.50-0.80	3.25-3.75
2340	0.35-0.45	0.60-0.90	3.25-3.75
2345	0.40-0.50	0.60-0.90	3.25-3.75
2350	0.45-0.55	0.60-0.90	3.25-3.75
2515	0.10-0.20	0.30-0.60	4.75-5.25

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

There are certain permissible temperature variations allowed for both Army and Navy work. Hardening temperature variations are acceptable so long as parts of the heavy cross section are hardened on the high side of the specified temperature range. Where it is satisfactorily demonstrated that the physical properties desired may be arrived at in some other fashion, a deviation on the part of the procurement agencies is usually granted upon application.

Tempering temperature variations are governed more or less by a "cut-and-try" method, which consists of tempering a sample somewhat below the temperature specified and then checking the hardness.



TABLE 47.—NICKEL-CHROMIUM STEELS\*

S.A.E. number	Carbon range	Manganese range	Nickel range	Chromium range
3115	0.10-0.20	0.30-0.60	1.00-0.50	0.45-0.75
3120	0.15-0.25	0.30-0.60	1.00-1.50	0.45-0.75
3125	0.20-0.30	0.50-0.80	1.00-1.50	0.45-0.75
3130	0.25-0.35	0.50-0.80	1.00-1.50	0.45-0.75
3135	0.30-0.40	0.50-0.80	1.00-1.50	0.45-0.75
3140	0.35-0.45	0.60-0.90	1.00-1.50	0.45-0.75
X3140	0.35-0.45	0.60-0.90	1.00-1.50	0.60-0.90
3145	0.40-0.50	0.60-0.90	1.00-1.50	0.45-0.75
3150	0.45-0.55	0.60-0.90	1.00-1.50	0.45-0.75
3215	0.10-0.20	0.30-0.60	1.50-2.00	0.90-1.25
3220	0.15-0.25	0.30-0.60	1.50-2.00	0.90-1.25
3230	0.25-0.35	0.30-0.60	1.50-2.00	0.90-1.25
3240	0.35-0.45	0.30-0.60	1.50-2.00	0.90-1.25
3245	0.40-0.50	0.30-0.60	1.50-2.00	0.90-1.25
3250	0.45-0.55	0.30-0.60	1.50-2.00	0.90-1.25
3312	Max. 0.17	0.30-0.60	3.25-3.75	1.25-1.75
3325	0.20-0.30	0.30-0.60	3.25-3.75	1.25-1.75
3335	0.30-0.40	0.30-0.60	3.25-3.75	1.25-1.75
3340	0.35-0.45	0.30-0.60	3.25-3.75	1.25-1.75
3415	0.10-0.20	0.30-0.60	2.75-3.25	0.60-0.95
3435	0.30-0.40	0.30-0.60	2.75-3.25	0.60-0.95
3450	0.45-0.55	0.30-0.60	2.75-3.25	0.60-0.95

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 48.—MOLYBDENUM STEELS\*

S.A.E. number	Carbon range	Manganese range	Chromium range	Nickel range	Molybdenum range
4130	0.25-0.35	0.50-0.80	0.50-0.80	—	0.15-0.25
X4130	0.25-0.35	0.40-0.60	0.80-1.10	—	0.15-0.25
4135	0.30-0.40	0.60-0.90	0.80-1.10	—	0.15-0.25
4140	0.35-0.45	0.60-0.90	0.80-1.10	—	0.15-0.25
4150	0.45-0.55	0.60-0.90	0.80-1.10	—	0.15-0.25
4340	0.35-0.45	0.50-0.80	0.50-0.80	1.50-2.00	0.30-0.40
4345	0.40-0.50	0.50-0.80	0.60-0.90	1.50-2.00	0.15-0.25
4615	0.10-0.20	0.40-0.70	—	1.65-2.00	0.20-0.30
4620	0.15-0.25	0.40-0.70	—	1.65-2.00	0.20-0.30
4640	0.35-0.45	0.50-0.80	—	1.65-2.00	0.20-0.30
4815	0.10-0.20	0.40-0.60	—	3.25-3.75	0.20-0.30
4820	0.15-0.25	0.40-0.60	—	3.25-3.75	0.20-0.30

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 49.—CHROMIUM STEELS\*

S.A.E. number	Carbon range	Manganese range	Phosphorus, max.	Sulphur, max.	Chromium range
5120	0.15-0.25	0.30-0.60	0.040	0.050	0.60-0.90
5140	0.35-0.45	0.60-0.90	0.040	0.050	0.80-1.10
5150	0.45-0.55	0.60-0.90	0.040	0.050	0.80-1.10
52100	0.95-1.10	0.20-0.50	0.030	0.035	1.20-1.50

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 50.—CHROMIUM-VANADIUM STEELS\*

S.A.E. number	Carbon range	Manganese range	Chromium range	Vanadium	
				Minimum	Desired
6115	0.10-0.20	0.30-0.60	0.80-1.10	0.15	0.18
6120	0.15-0.25	0.30-0.60	0.80-1.10	0.15	0.18
6125	0.20-0.30	0.60-0.90	0.80-1.10	0.15	0.18
6130	0.25-0.35	0.60-0.90	0.80-1.10	0.15	0.18
6135	0.30-0.40	0.60-0.90	0.80-1.10	0.15	0.18
6140	0.35-0.45	0.60-0.90	0.80-1.10	0.15	0.18
6145	0.40-0.50	0.60-0.90	0.80-1.10	0.15	0.18
6150	0.45-0.55	0.60-0.90	0.80-1.10	0.15	0.18
6195(c)	0.90-1.05	0.20-0.45	0.80-1.10	0.15	0.18

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 51.—TUNGSTEN STEELS\*

S A E. number	Carbon range	Manganese, max.	Chromium range	Tungsten range
71360	0.50-0.70	0.30	3.00-4.00	12.00-15.00
71660	0.50-0.70	0.30	3.00-4.00	15.00-18.00
7260	0.50-0.70	0.30	0.50-1.00	1.50- 2.00

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 52.—SILICON-MANGANESE STEELS\*

S.A.E. number	Carbon range	Manganese range	Silicon range
9255	0.50-0.60	0.60-0.90	1.80-2.20
9260	0.55-0.65	0.60-0.90	1.80-2.20

\* "Metals Handbook," A.S.M. Charts for S.A.E. Steels, copyrighted, 1935, Society of Automotive Engineers, Inc.

TABLE 53.—HEAT-TREATMENT RANGE FOR AIRCRAFT STEELS\*

S.A.E. numbers	Temperatures, °F.				Rockwell range, 70,000 p.s.i. requirement
	Normalize	Anneal	Harden	Temper	
1025	1625-1675-A	1575-1600-A	1575-1600†	1150-A	
1035	1575-1625-A	1525-1550-F	1525-1575-W	690-1300	C-21-B-88
1045	1525-1575-A	1450-1457-F	1500-1550-O	690-1325	C-24-B-94
1095	1525-1575-A	1450-1475-F	1450-1500-O	690-1150	C-45-C-35
2330	1475-1525-A	1425-1450-F	1450-1475-O	550-1210	C-45-B-93
2340	1475-1525-A	1428-1450-F	1425-1475-O	525-1300	C-45-B-92
3135	1525-1575-A	1475-1500-F	1475-1525-O	650-1225	C-43-B-97
3140	1500-1550-A	1450-1475-F	1475-1525-O	675-1225	C-44-C-21
3250	1475-1525-A	1425-1450-F	1425-1475-O	725-1375	C-46-C-20
3335	1500-1550-A	1425-1450-F	1425-1475-O	675-1300	C-44-B-96
3435	1500-1550-A	1450-1475-F	1425-1475-O	610-1225	C-45-C-23
4130	1600-1650-A	1525-1550-F	1575-1625-O	550-1210	C-44-B-96
4140	1575-1625-A	1525-1556-F	1525-1575-O	575-1260	C-45-C-21
4150	1550-1600-A	1500-1525-F	1500-1550-O	790-1260	C-49-C-24
4340	1525-1575-A	1475-1500-F	1475-1525-O	680-1300	C-47-C-27
6135	1575-1625-A	1525-1550-F	1550-1575-O	550-1300	C-44-B-96
6150	1550-1600-A	1500-1525-F	1525-1550-O	680-1300	C-50-C-24
6195		1525-1550-F	1500-1550-O	350-2Hr-(A)	C-57-C-63

\* U.S. Navy PH-5.

† For aircraft nuts only.

A = cool in air.

F = cool in furnace to 900°F.

W = quench in water.

Q = quench in oil.

TABLE 54.—CORROSION AND HEAT-RESISTING ALLOYS\*

S.A.E. number	Carbon range	Manganese range	Chromium range	Nickel range
30905	0.08 max.	0.20-0.70	17.00-20.00	8.00-10.00
30915	0.90-0.20	0.20-0.70	17.00-20.00	8.00-10.00
51210	0.12 max.	0.60 max.	11.50-13.00	
X51410	0.12 max.	0.60 max.	13.00-15.00	
51335	0.25-0.40	0.60 max.	12.00-14.00	
51510	0.12 max.	0.60 max.	14.00-16.00	
51710	0.12 max.	0.60 max.	16.00-18.00	

\* See Notes for Tables of Chemical Composition (e), immediately following.

## NOTES FOR TABLES OF CHEMICAL COMPOSITION

a. Silicon range of all S.A.E. basic open-hearth alloy steels shall be 0.15 to 0.30 per cent. For electric-furnace alloy steels and acid open-hearth alloy steels, the silicon content shall be 0.15 per cent minimum.

b. Phosphorus and sulphur in all S.A.E. nickel steels, nickel-chromium steels, molybdenum steels, and silicon-manganese steels shall be 0.040 per cent maximum and 0.050 per cent maximum, respectively.

c. Phosphorus in all S.A.E. chromium-vanadium steels shall be 0.040 per cent maximum except in No. 6195, which shall be 0.030 per cent maximum. Sulphur in all S.A.E. chromium-vanadium steels shall be 0.050 per cent maximum except in No. 6195, which shall be 0.035 per cent maximum.

d. Phosphorus and sulphur in all S.A.E. tungsten steels shall be 0.035 and 0.040 per cent maximum, respectively.

e. Silicon shall be 0.05 per cent maximum except in alloys 30905 and 30915, which may be 0.78 per cent maximum. Phosphorus shall be 0.030 per cent maximum in all corrosion- and heat-resisting alloys. Sulphur shall be 0.030 per cent maximum in all except in the free-cutting alloy X51410, which shall be in the range 0.15 to 0.50 per cent.

A general rule follows that the higher the temperature the lower the hardness. Usually the tempering temperature should not be more than 200°F. below the temperature specified for the particular type of steel involved.

In the preceding paragraph, we have spoken of the period for the hardening, normalizing, and annealing of steel. Navy specification Ph-5b includes a chart shown in Tables 53 and 54 for a characteristic application of the time required. The necessary time involved for tempering should not be less than 1 hr.

Inspection considerations and physical test for the proof of proper heat-treatment procedure is given in detail in the following chapters.

## CHAPTER XVI

### X-RAY INSPECTION OF CASTINGS AND FORGINGS

The science of X ray is far too technically involved to discuss in detail in a book devoted to process practices. The technical application of X ray, although basically the same among different companies, varies to some extent with the subject. Therefore, in this chapter, the use of X-ray examination of metal castings and forgings is discussed as nearly in lay terms as possible without bordering on confusion through the use of unfamiliar technical terms.

Undoubtedly the best references for the application of industrial X rays offered to the student of X-ray technology are the various editions of "Applied X Rays," by George L. Clark, assistant Professor of applied chemical research in the Massachusetts Institute of Technology. Numerous investigators in the X-ray field, such as Clark, H. H. Lester, Corrigan, Davey, Edwards, and Frary have definitely proved the value of the application of both radiography and diffraction methods.

There are two main industrial applications of the X ray, *viz.*, radiography and diffraction. Radiographic X-ray examinations are the most commonly applied in industrial research and control. The majority of aircraft castings and forgings are produced under radiographic X-ray control. Radiographic examination and control are requirements of Federal specification AN-QQ-M-181 and Army Air Corps specification 20026. This control consists of the radiographic examination of gating, pouring, and other foundry practices and methods to determine a production free from internal defects.

The basic of radiographic X ray is defined by Clark as "passing of beams of X rays through the object to be examined and by means of a fluorescent screen or photographic plate, recording the varying intensities of the emergent beam and thus obtaining a shadow picture of the interior of the object." Although it is true that X rays consist of short wave lengths and are much more adaptable to the penetration of matter than ordinary light sources, they still have a different rate of absorption, influenced by the substances involved. All materials do not possess the same transparency factors to X rays. It is upon this principle that radiographic X-ray technique is founded. In the X-ray shadow picture for the radiographic determination of inclusions, slag, etc., the ability of perfect metal to allow the penetration of the X rays and the subsequent

blocking of the X rays by imperfect metal brings about a difference in the X-ray picture, outlining the fact that a defect is present.

#### **RADIOGRAPHIC EXAMINATION OF METAL CASTINGS AND FORGINGS**

An example of the specification requirements of X ray is well evidenced by the later issue of U.S. Army specification 57-74-1c for magnesium-alloy sand castings for aircraft. This specification requires that castings shall be produced under X-ray control that must give results consistent with good foundry practice and evidence proper foundry technique. It further provides that if the X-ray examination reveals the presence of injurious defects, the lot as a whole should be rejected. By the operation of this control, the casting technique producing castings free from blowholes, pipes, etc., is developed.

The defects ordinarily produced by a radiographic examination can be grouped into the following classes:

1. Slag inclusion.
2. Pipes.
3. Sand inclusions.
4. Cracks.
5. Segregation of the metal.
6. Gas cavities (which might be due to the liberation of gases from the hot metal or from the mold).
7. Porosity (due to shrinkage or residual chemical reaction).

Practically all the foregoing defects are eliminated by proper foundry technique and procedure.

To prescribe a specific radiographic X-ray technique would not be dependable, for definite recommendations vary with the subject. However, one or two important factors are observed in all cases. Selection of the sections to be X-rayed should be carefully made on the basis of the importance of the section to the structural significance of the parts. Clark recommends that an ordinary photograph of the selected section be made for the purpose of later identification on the radiographs, which, in turn, may be individually identified by placing lead numerals on the piece or section before taking the radiograph.

Protection of all the film from excessive radiation must be observed at all times. This may be accomplished by the use of lead sheet. A secondary radiation from near-by objects will tend only to confuse the picture and fog the film.

The quality of pictures being dependent on thickness of section, the use of various types of screens, etc., must be individually taken up as the case presents itself.

Radiographic X ray resolves itself as a quick, efficient method for visual examination without destruction. It should be understood

here that X-ray radiographic pictures are an indication and form only the basis for the established metallographic examination methods.

### X-RAY DIFFRACTION OF INTERNAL STRUCTURES

The use of X-ray diffraction methods for the study of interior crystal structure of castings and forgings is paradoxically new and old. Whereas radiographic methods are based on the passing of the X-ray beams through the object for resultant shadow pictures, diffraction methods are based on the crystalline structure and its arrangement for ultimate reflection of the X-ray beams, bringing about a picture showing the orientation of the crystals within the structure itself.

Laue, Bragg, Clark, and many other investigators have offered diffraction results that definitely place diffraction X ray as a method for determining internal structure and stress of metal castings and forgings.

To understand diffraction X ray completely, one must understand the study of crystalline matter. As explained before, it is not intended to expound technical knowledge on the science of X ray in this chapter. On the other hand, however, it is intended to explain its use in industrial application.

The most important use of diffraction methods and their application to castings and forgings are in obtaining a knowledge of original fiber structure and the resultant distortion of fiber arrangement due to heat treatment, forming, and cold working. The crystalline structure of the fiber composition of cast and forged parts evidences itself when stress and fatigue failures are studied. Forecasting these failures with some degree of accuracy brings to the investigator a knowledge heretofore unobtainable.

If the X-ray study of grain structure is excluded, an insight into the mechanics of plastic deformation of crystal aggregates becomes necessary in understanding the behavior of the aggregates in deformation due to forming and working.

The fiber structure is simply a preferred orientation of the grains that indicates directional properties. This is predicated on two extremes:

1. A single crystal definitely oriented produces diffraction spots.
2. Powder of single crystals in chaotic array produces concentric rings. The intermediate state in which the powder or the aggregate approaches the singular or crystalline condition by the position of alignment causes the particles to take up a common direction with respect to the incident beam of the X ray.

In an uninjured crystal pattern or lattice, the plane of the crystals acts as a mirror so that the images of the narrow aperture operated caused by the plane are sharp elliptical spots on the plate or film. If, however, the crystal is stressed beyond its elastic limit, translation of

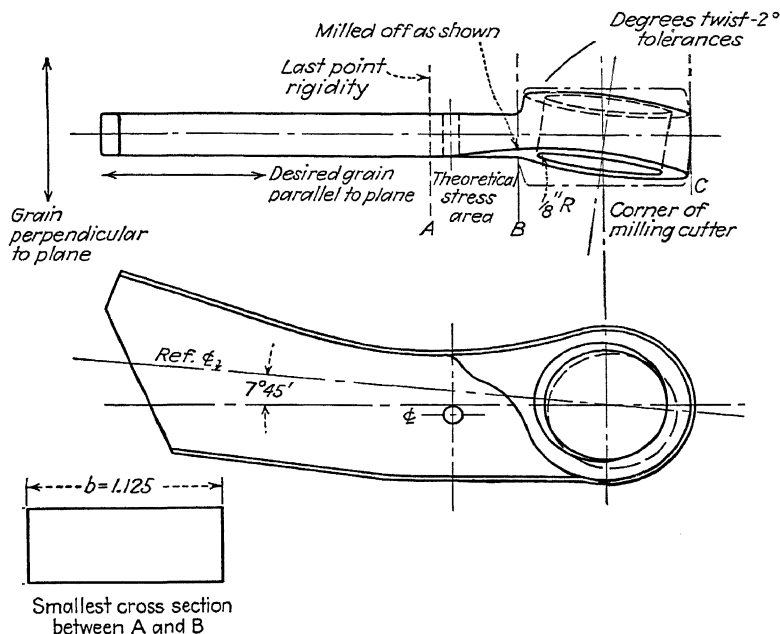


FIG. 17.—Flap-hinge fitting (14ST aluminum-alloy forging).

## RESIDUAL STRESS DUE TO 2-DEG. TWIST

Formula for twist of rectangular shaft (Timoshenko):

$$S \text{ max.} = \frac{\theta \beta c G}{\alpha}$$

$$- b/c = 3.0 \text{ (factor)}$$

$$\alpha = 0.267 \text{ (Timoshenko)}$$

$$\beta = 0.263$$

Angle of twist = 2 deg. over 2.25 in. (AC)

$$= \frac{2}{2.25} = 0.890 = 0.0155 \text{ radian}$$

 $G = 3,800,000$  p.s.i. or modulus of elasticity in shear

$$\text{Maximum residual stress} = \frac{(0.0155)(0.263)(0.375)(3,800,000)}{0.267} = 21,900 \text{ p.s.i.}$$

Minimum yield for 14ST = 38,000 p.s.i.

Ultimate strength = 45,000 p.s.i.



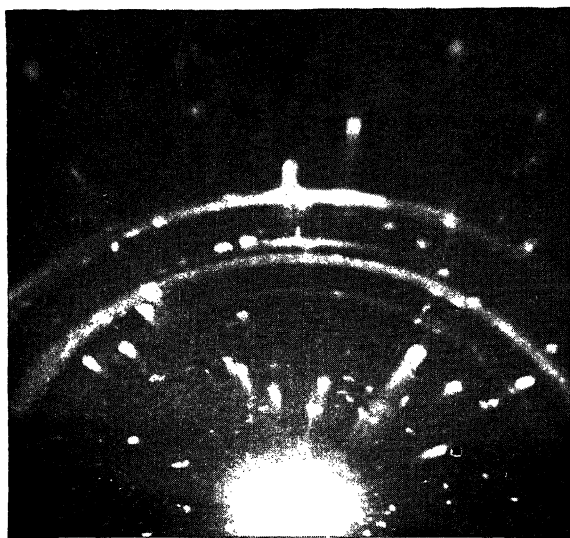


FIG. 18.—Surface at *width* of part between points *A* and *B* (see Fig. 17) *prior* to twisting 2 deg.

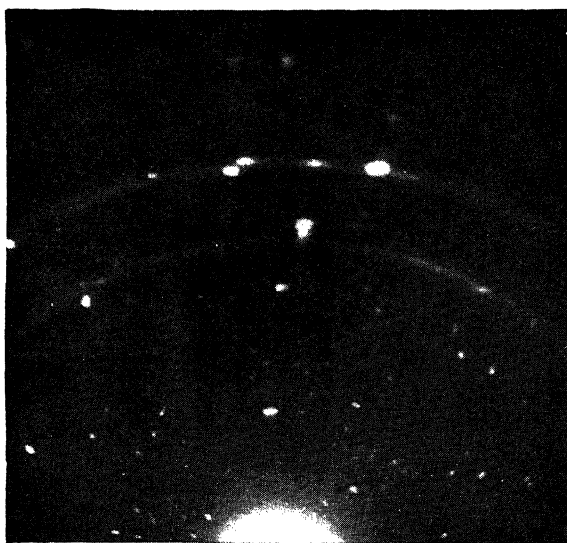


FIG. 19.—Surface at *width* of part between points *A* and *B* (see Fig. 17) *after* twisting 2 deg.

its position is based on a slip plane. This distorts its reflected or transmitted image. This distortion of the plane manifests itself much as the reflection from a cylindrical mirror.

If the bending axis is taken normal to the slip direction and parallel to the slip plane at an angle less than 45 deg. to the X-ray plate or film, then the distortions of the interference spot occur on curves that pass through the central direct-beam image. The continuous series of point images that appear are classed as asterism striations. These are radial

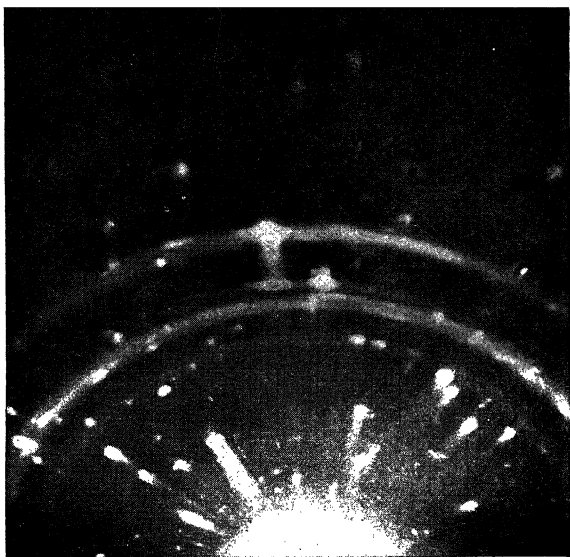


Fig. 20.—Surface at thickness of part between points A and B (see Fig. 17) prior to twisting 2 deg.

in nature. By monochromatic light, these radial striations appear only partially and reach a sharply defined limit at some distance from the central spot.

By the occurrence of such radial striations, it is concluded that the crystal structure has been stressed beyond the elastic limit and the resulting residual stress so indicated through translation by slip-plane distortion of the image.

In the definition of grain direction and fiber structure, the diffraction result when fiber structure is placed perpendicular to the X-ray beam, parallel to the plane of the surface examination, shows maximum fibering interference.

When fiber structure is placed parallel to the X-ray beam but perpendicular to the plane of the surface, random grain structure appears with a minimum of fibering interference. We have, therefore, by the simple rules given above, established two reasons and modes of examination:

1. Examination for stress.
2. Examination for grain direction and fiber structure.

An interesting example of application of diffraction X ray to the study of both points is illustrated by the investigation of the part shown in



FIG. 21.—Surface at thickness of part between points A and B (see Fig. 17) after twisting 2 deg.

Fig. 17. This part is made from aluminum-alloy 14S, meeting Navy specification 46A7. It is, of course, heat-treated to "ST" condition and was designed to be used as a flap-hinge fitting. It became necessary, on installation, to twist the part from A to C from 2 to 4 deg. This deformation was done without an annealing operation. In other words, the deformation was made by cold working. An investigation was made to determine the residual stress due to a 2-deg. minimum twist. The figures for the problem are given in Fig. 17. An X-ray diffraction examination, the results of which are shown in Figs. 18 and 19, was also made of the part. As will be noticed, these pictures were made on the surface confined between points A and B, shown in the drawing.



FIG. 22.—Inside the *sectioned width* after twisting 2 deg.

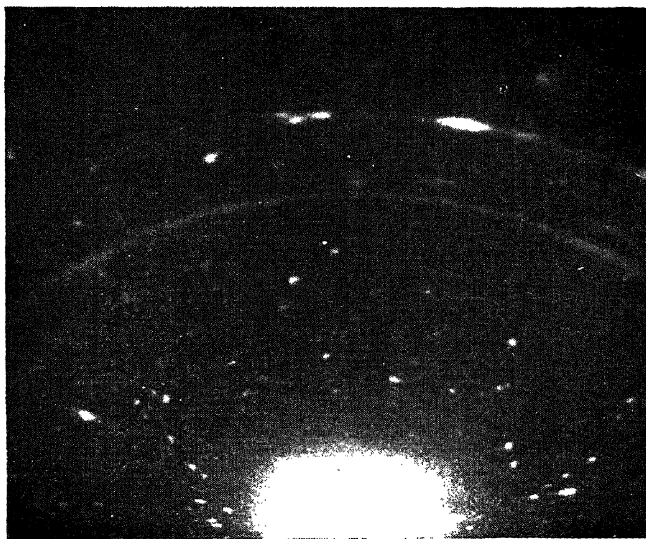


FIG. 23.—Inside the *sectioned thickness* after twisting 2 deg.

Two of these forgings were used in the examination. One had been cold-worked, and one had not. The X rays, of course, were taken of both parts between the points mentioned. As can be seen by examining the photograph of the unworked and worked surface, the unworked surface shows a certain amount of residual stress, undoubtedly due to the forging operation evidenced by the "tails" of light reflected from the stressed grain structure placed on a slip plane. However, it will be noticed that there are definite concentric rings. By contrast, an examina-

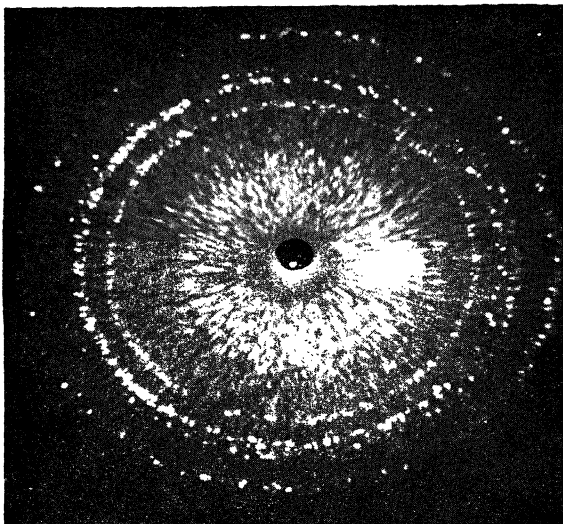


FIG. 24a.—Transmission of section from AB (see Fig. 17) prior to twisting 2 deg.

tion of the worked surface photograph shows practically no reflection of spots, a definite scattering of arrangement, and a dispersion of the concentric rings. It might be stated that the X-ray beam in these two photographs was directed through the top or flat side of the forging. In the photographs showing the worked and unworked surface, the same result is obtained, but it is shown in a much lesser degree. The X-ray beam was directed through the side of the forging or the thin section.

The part was sectioned between A and B and a photograph taken of the inside, which is shown by Fig. 22, worked inside, and Fig. 23, worked inside, which further substantiates the fact that the stress is continuous throughout the thickness of the section. The part was further sectioned and various shots taken of the transmission type. These are shown by Figs. 24a to 24g, transmission photographs, which further

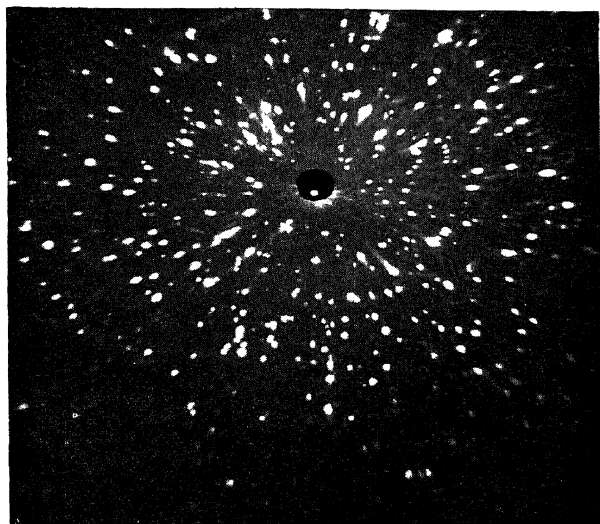


FIG. 24*b*.

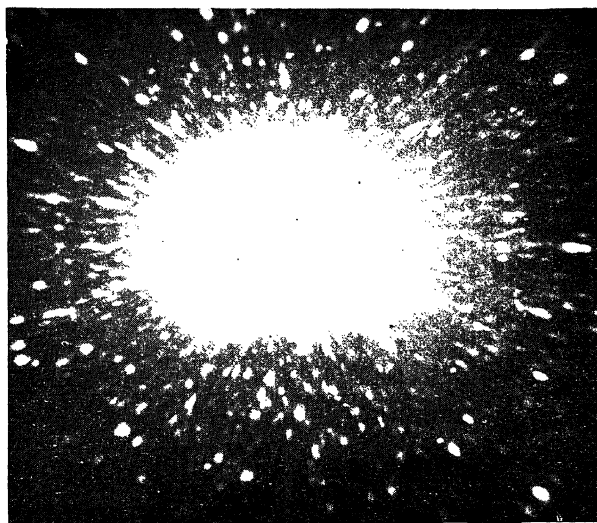


FIG. 24*c*.

FIGS. 24*b*-24*g*. Transmission of section from *AB* (see Fig. 17) after twisting 2 deg.

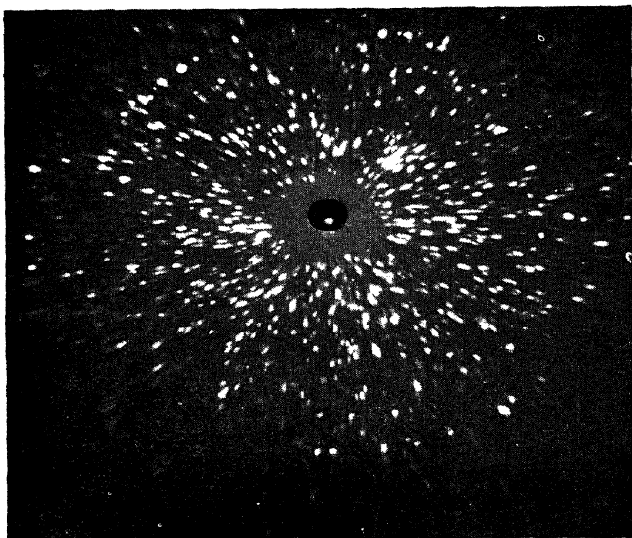


FIG. 24d.

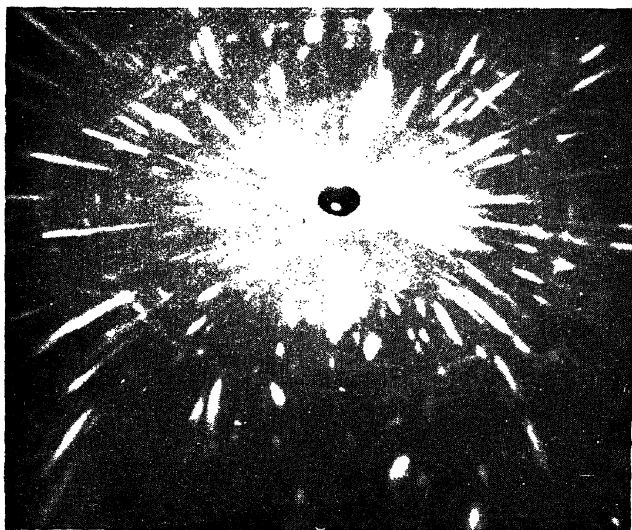


FIG. 24e.

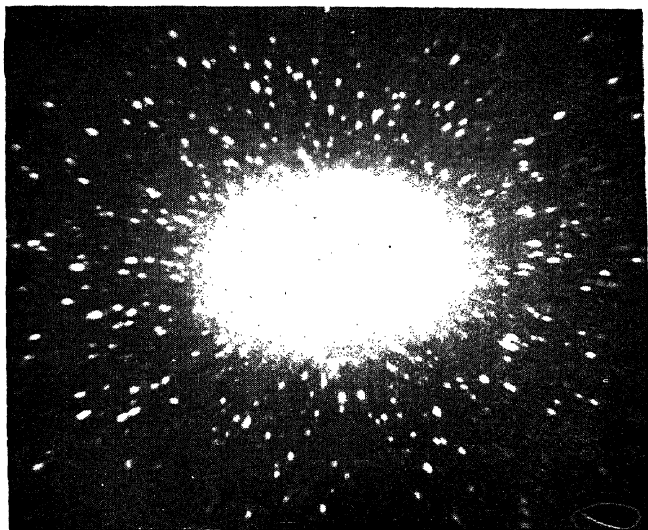


FIG. 24f.

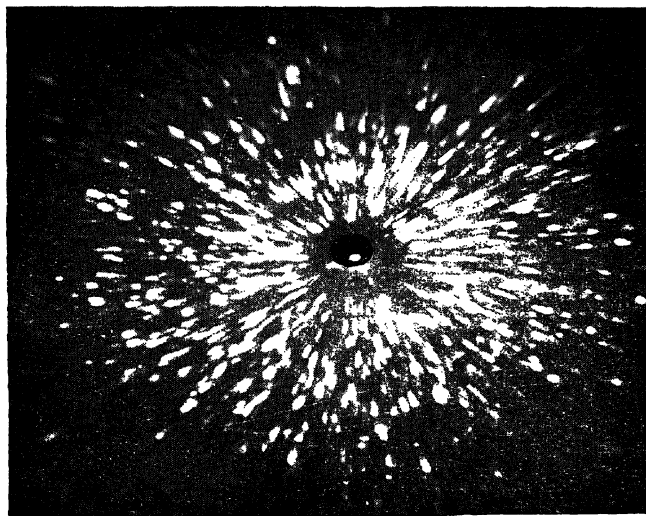


FIG. 24g.



indicate residual stress, as well as a minimum of fiber interference, showing that the fiber structure is perpendicular to the plane rather than in the desired parallel state.

The result of having proper grain direction in a part whose position is established at the zero rib station in a wing is easily recognized through the fact that it is in this region that most peak loads are carried. An example of having the grain structure perpendicular to the plane in a part of this type could be illustrated by the strength of a bundle of sticks. Place a bundle of sticks before you perpendicularly to the ground, and pull the bundle apart. Their perpendicular position allows easy separation. On the other hand, place the bundle in a horizontal position. In this position, it is necessary to break each individual stick in order to cause separation.

In General Specification for Inspection of Material, Appendix II, Metals, Part *F*, Radiography, Section *F-I*, Definitions and Radiographic Requirements Issued by the Navy Department, Dec. 1, 1938, some very helpful definitions are given that are repeated here.

In the general requirements acceptable by both branches of the service, the following points, if observed, will be found applicable:

1. *Films*.—In general, films used should be of the non-inflammable type, sensitized on both sides.

2. *Cassettes*.—Intensifying screens gamma-ray films should be prepared by using lead-intensifying screens. X-ray films should also be prepared in this manner when the use of calcium tungstate intensifying screens is impractical.

3. *Penetrameters*.—Radiographic examinations should be made in such a way that they will be capable of indicating defects in depths equal to 2 per cent of the thickness of the metal being examined. In order to accomplish this, penetrameters composed of material having a density that approximates material being X-rayed should be used.

4. *Limit Distances*.—During exposure, the film should be as close to the surface of the metal as is possible. Allowances should be made for gamma rays in radiographing flat surfaces or cylinders.

5. *Film-processing Defects*.—Film should be processed in such a manner that defects will be eliminated that might cause misinterpretation of the X-ray results.

## CHAPTER XVII

### METHODS FOR PHYSICAL TESTING OF METALS

Specific information regarding the standard testing and inspection of metals for military and naval aircraft has been standardized between the two branches of the service.

The selection of test specimens for testing and inspection is of prime importance. The test samples selected must at all times be selected to represent the quality of the metal involved. If, in such cases, the test specimens selected are not sectioned or obtained as an integral part of the metal that they represent, a sample identical with the material involved should be selected and subjected to the same treatment and processes as the material represented.

When test metals are an integral part of the material under consideration, test samples should not be cut off or otherwise removed until the pieces from which they are cut have received the full process procedure prescribed for their treatment, as well as complete machining operations required by design.

The condition of the test specimen selected is also of prime importance. It should be clean, dry, and free from foreign matter. If drillings and millings are used, they should be taken at slow speeds to eliminate possibility of oxidation.

Military and naval requirements specify that for means of identification, a tag containing the following information should be attached to each sample and a subsequent record kept as designated:

1. Name and address of vendor.
2. Control number.
3. Name of material.
4. Quality of material.
5. The applicable specification.
6. The date of manufacture.
7. The manufacturers lot, batch, case, or heat number.
8. The applicable company's designation or specification number (user).

Hardness tests may be obtained by either the Rockwell or Brinell method. If Rockwell test methods are used, the following procedure should be observed:

1. The samples shall be free and clean from scale and other surface irregularities and must lie flat upon the anvil. For soft specimens, the

*B* or black scale should be used. Soft specimens usually include those less than 30 on the *C* scale. An average of a number of readings should be made and this average taken as the hardness number.

2. The Rockwell results must be represented by the number and the prefix involved.

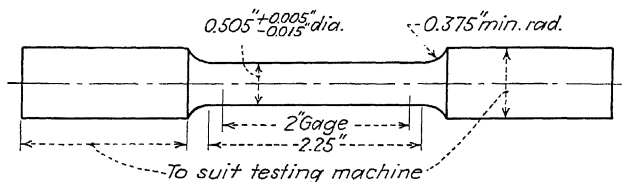
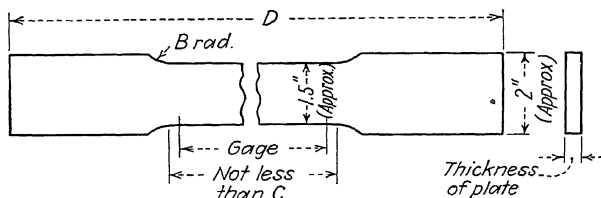


FIG. 25.—Type 1. Tensile specimen.



When gage = 2:  $B = \text{Not less than } 0.25"$   
 $C = 2.25"$

$D = \text{Not less than } 9"$

When gage = 8:  $B = \text{Not less than } 1"$   
 $C = 9"$

$D = \text{Not less than } 15"$

FIG. 26.—Type 2. Tensile specimen.

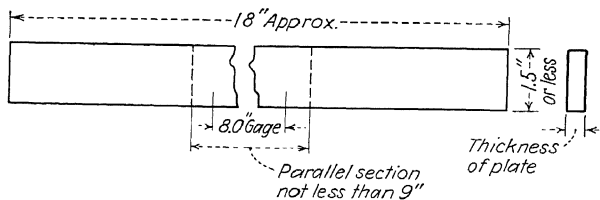


FIG. 27.—Type 3. Tensile specimen.

If the Brinell test methods are used, the thickness of the specimen should present a surface on the face, free from bulges and indentations. Curved specimens should not present a radius less than 1 in. The load to be applied must be applied steadily, without spasmodic jerks, at such a rate that approximately 3 sec. is required from the time of contact between the ball and the specimen until the point of reaching the maximum load. The maximum load should be applied for not less than 15 sec.

The distance of the center of the indentation from the edge of the specimen or from the center of another indentation should not be less than three times the diameter of the indentation. The indentation diameter shall be taken as the average of the two mutually perpendicular diameters. The diameter of the indentation on curve specimens should be taken as the average of the two principal diameters.

Tensile tests are again of prime importance to strength of the material involved. Standard tensile-test specimens are of five types:

Type 1 is circular in cross section and is used for bars, rods, forgings, plates, shapes, heavy-walled tubing, and casings (see Fig. 25).

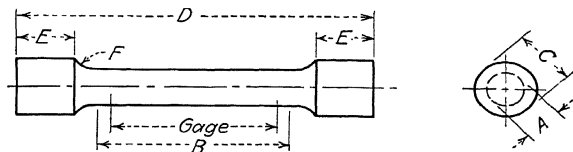


FIG. 28.—Type 4. Tensile specimen.

#### AREA DIMENSIONS

$A \pm 2\%$ , in.	Gauge, in.	$B$ , in.	$C \pm 0.015$ , in.	$D$ approximate, in.	$E$ approximate, in.	$F$ radius min., in.
0.437	1.75	2.0	0.562	3.75	0.625	0.375
0.357	1.4	1.75	0.5	3.5	0.625	0.28
0.252	1.0	1.25	0.375	3.0	0.625	0.18
0.113	0.4	0.625	0.25	1.625	0.375	0.09

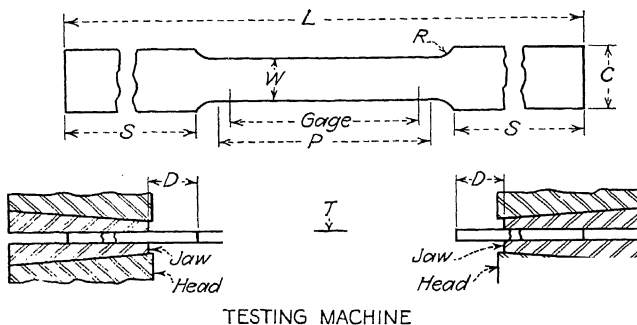
Type 2 is rectangular in cross section and is used for flat material over  $\frac{3}{8}$ -in. stock (see Fig. 26).

Type 3 is rectangular in cross section and is used for flat material over  $\frac{3}{8}$  in. thick where the width of the material is not sufficient for Type 2 (see Fig. 27).

Type 4 is circular in cross section, and the reduced section is geometrically similar to Type 1. This type is used for materials having dimensions insufficient for Type 1 (see Fig. 28).

Type 5 is rectangular in cross section and is used for flat material not over  $\frac{1}{2}$  in. thick (see Fig. 29).

All specimens should be strictly straight. Before the specimen is tested, a gauge mark shall be placed at each end of the gauge length and also two scribe marks in the gauge length at one-quarter of the gauge length from each gauge mark. (The scribe marks are to indicate whether the break occurs within the middle half of the gauge length.) The gauge length and cross-sectional area at the smallest section of the test specimen should be recorded.



TESTING MACHINE  
FIG. 29.—Type 5. Tensile specimen.

#### CALCULATION FOR AREA

Dimension	Sheet thickness	
	(3) $\frac{1}{4}$ in. and less	$\frac{1}{4}$ – $\frac{1}{2}$ in.
$C$ (max.) (2)	$1.5 \times W$	$1.5 \times W$
$D$ (min.) (1)	$W$	$W$
Gauge	2 or 4 in.	2 or 4 in.
$L$ (min.)	9 or 11 in.	9 or 11 in.
$P$ (min.)	$1.125 \times G$	$1.125 \times G$
$R$ (min.)	$W$	$W$
$S$ (approximate)	3 in.	3 in.
$T$	Sheet thickness	Sheet thickness
$W$	$\frac{1}{2}$ in. = 0.010 in.	$\frac{3}{4}$ in. = 0.015 in.

NOTE 1.—Specimens may be reduced to width  $W$  at center of gauge length (by draw-filing) not more than 0.004 in. when  $W$  equals  $\frac{1}{2}$  in. and 0.006 in. when  $W$  equals  $\frac{3}{4}$  in.

NOTE 2.—In testing thin sheet metal, the tendency to tear and break near the shoulders can be reduced by making  $C$  not greater than  $1.13 \times W$ .

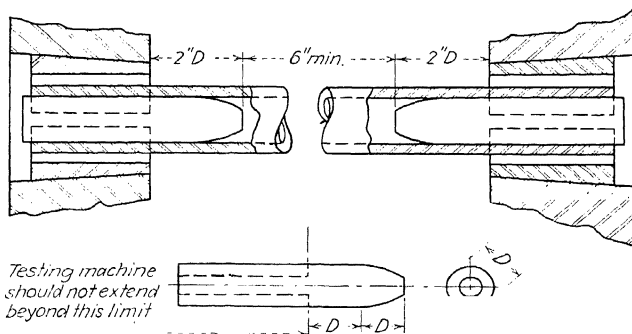


FIG. 30.—Plugged-tube tensile specimen.

Whenever practicable, rods, bars, shapes, and wire may be tested in full size, the cross section of the specimen being the full cross section of the material. To obtain elongation value approximately equivalent to that obtained with Type 1 specimens, the gauge length should be  $4.5 \times$  the sectional area. For circular sections, a gauge length of  $4 \times$  the diameter may be used.

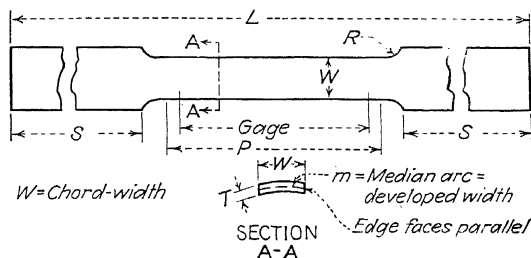


FIG. 31.—Type 5A. Tensile specimen.

#### CALCULATION FOR AREA

Dimension	Wall thickness	
	$\frac{1}{4}$ in. and less	$\frac{1}{4}$ – $\frac{1}{2}$ in.
$C$ (max.)	$1.5 \times W$	$1.5 \times W$
$D$ (min.)	$W$	$W$
Gauge	2 or 4 in.	2 or 4 in.
$L$ (min.)	9 or 11 in.	9 or 11 in.
$P$ (min.)	$1.125 \times G$	$1.125 \times G$
$R$ (min.)	$W$	$W$
$S$ (approximate)	3 in.	3 in.
$T$	Wall thickness	Wall thickness
$W$	$\frac{1}{2}$ in. $\pm 0.010$ in.	$\frac{3}{4}$ in. $\pm 0.015$ in.

Formula for calculation of cross-sectional area:

$$\begin{aligned}
 D - T &= d \\
 W &= d \sin \theta_2 \\
 m &= dX \theta_2 \text{ (in radians)} \\
 \text{Cross-sectional area} &= mXT
 \end{aligned}$$

where  $D$  = O.D. of tube.

$T$  = wall thickness of tube.

$W$  = chord width of specimen.

$d$  = median diameter of tube.

$\theta$  = Central angle subtended by  $m$ .

$m$  = median arc or developed width of specimen.

The value of  $m$ , for specimens from tubes of sizes indicated, may be obtained by adding the following percentages of  $W$  (page 190) to the actual chord width of the specimen.

CORRECTION TABLE FOR DEVELOPED WIDTH PERCENTAGE OF  $W$  TO BE ADDED

Tube diameter, in.	Percentage of $W$ to be added				
	0.035-in. wall thickness	0.083-in. wall thickness	0.120-in. wall thickness	0.87-in. wall thickness	0.250-in. wall thickness
Where $W = 0.5$ in.:					
1.....	5.1	5.8	6.4	7.7	9.5
1 $\frac{1}{4}$ .....	3.1	3.3	3.6	4.1	4.7
1 $\frac{1}{2}$ .....	2.1	2.2	2.3	2.6	2.9
1 $\frac{3}{4}$ .....	1.3	1.5	1.6	1.8	1.9
2.....	1.0	1.1	1.2	1.3	1.4
2 $\frac{1}{4}$ .....	0.8	0.9	0.9	1.0	1.4
2 $\frac{1}{2}$ .....	0.6	0.7	0.7	0.8	0.8
2 $\frac{3}{4}$ .....	0.5	0.5	0.6	0.6	0.7
3.....	0.5	0.5	0.5	0.5	0.6
3 $\frac{1}{2}$ .....	0.3	0.3	0.4	0.4	0.4
4.....	0.2	0.3	0.3	0.3	0.4
Where $W = 0.75$ in.:					
2.....	2.7	2.7	2.9	3.1	3.4
2 $\frac{1}{4}$ .....	2.0	2.19	2.2	2.3	2.5
2 $\frac{1}{2}$ .....	1.6	1.7	1.7	1.8	1.9
2 $\frac{3}{4}$ .....	1.3	1.4	1.4	1.5	1.6
3.....	1.1	1.1	1.2	1.3	1.3
3 $\frac{1}{2}$ .....	0.8	0.8	0.9	0.9	0.9
4.....	0.6	0.6	0.7	0.7	0.8

Whenever practicable, tubing should be tested in full section, with the ends plugged, so that the tube may be gripped without being crushed (see Fig. 30). When it is impractical to test a full section of tubing, a section parallel to the axis may be cut out and prepared for testing. Except for heavy-walled tubing, Type 5 or Type 5A specimen shall be used. If Type 5 is to be used, the entire section of tubing may be flattened with a soft-faced hammer prior to marking the specimen. If Type 5A is used, the ends of the specimen may be flattened with a soft-faced hammer, but no flattening shall be performed on the gauge length. For heavy-walled tubing, Type 1 or Type 4 specimens may be used.

The load should be applied at such a rate of speed that it is accurately indicated at all times. The load required to fracture the specimen should be recorded. If the fracture occurs outside the scribe marks indicating the middle half of the specimen tested, the specimen should be discarded and another one tested.

Percentage elongation in the tensile strength, in pounds per square inch, is the load required to fracture the specimen divided by the original cross-sectional area.

The broken halves of the specimen should be fitted together as cleanly as possible and the new gauge length measured. The percentage elongation may be calculated from the following formula, where  $g$  = original gauge length and  $g_1$  = new gauge length:

$$\text{Percentage elongation} = \frac{g_1 - g}{g} \times 100$$

The cross-sectional area at the point of fracture should be determined. The percentage reduction of area may be calculated from the following

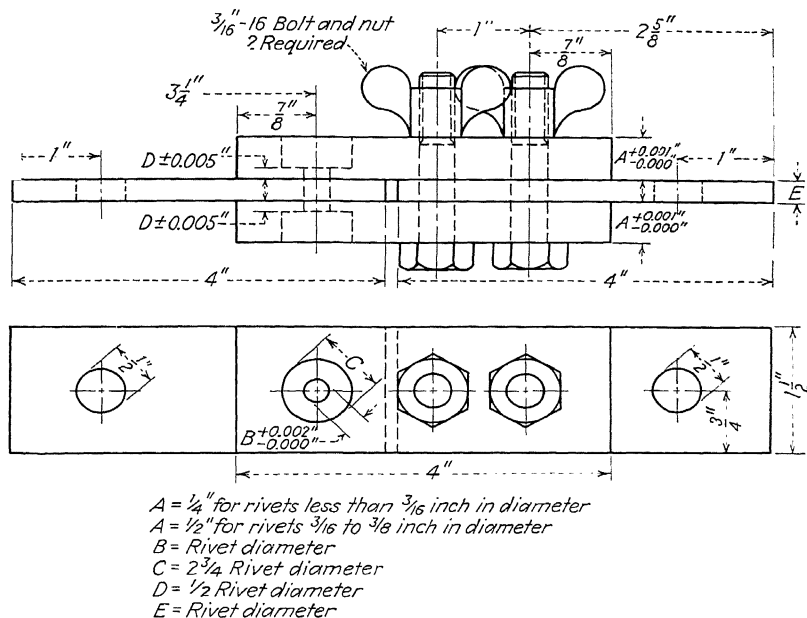


FIG. 32.—Shear test fixture for the physical shear testing of rivets.

formula, where  $A$  = original cross-sectional area and  $A_1$  = cross-sectional area at point of fracture:

$$\text{Percentage reduction of area} = \frac{A - A_1}{A} \times 100$$

For round specimens where  $d$  = original diameter and  $d_1$  = diameter at point of fracture

$$\text{Percentage reduction of area} = \frac{d^2 - d_1^2}{d^2} \times 100$$



The bending test applies itself differently depending upon the shape of the material to be tested.

**Bars, Rods, and Wire.**—Whenever practicable for bars, rods, and wire not exceeding  $1\frac{1}{2}$  in. in the smallest lateral dimension, the specimen shall be a full section of the material not less than 6 in. in length.

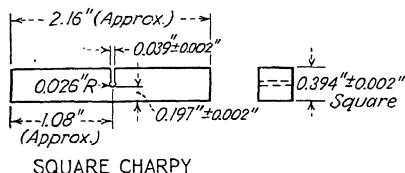
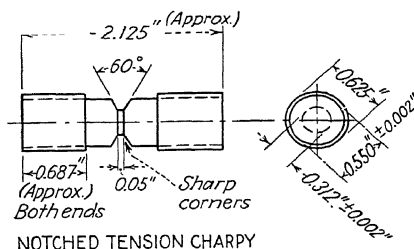


FIG. 33.—Charpy notched and square specimens.

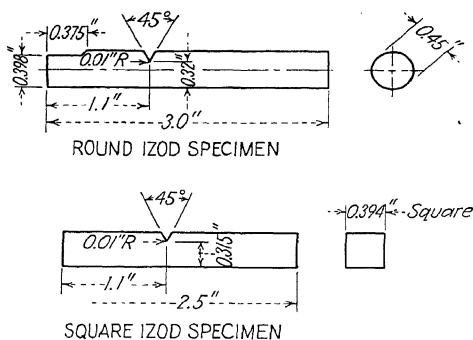


FIG. 34.—Round and square Izod specimens.

**Flat Material.**—For flat material not exceeding  $\frac{1}{2}$  in. in nominal thickness, the thickness of the specimen shall be that of the material, the width shall be not less than  $\frac{3}{4}$  in., or the width of the material less than  $\frac{3}{4}$  in. wide; and whenever practical, the length shall not be less than 6 in.

*Machined Specimens.*—For material exceeding  $\frac{1}{2}$  in. in nominal thickness or exceeding  $1\frac{1}{2}$  in. in nominal diameter, the specimen shall be machined from the material. The thickness of the specimen shall be  $\frac{1}{2}$  in., the width 1 in., and the length not less than 6 in. For material not less than  $1\frac{1}{2}$  in. in nominal diameter or thickness, the axis of the specimen shall be one-fourth the diameter or thickness from the surface of the material.

Charpy and Izod impact-test specimens should conform to Figs. 33 and 34. For the notched tension, Charpy impact test specimens with Fig. 33 for the square specimen as required, Izod impact-test specimen should conform with Fig. 34 as required.

The methods given here are in strict conformance with military and naval requirements, and if the instructions are used as given, they will be found generally acceptable to the procurement agencies.

## CHAPTER XVIII

### CHARACTERISTIC QUALIFICATION TEST FOR ARMY AND NAVY WELDERS

It has been an established practice for the Army and Navy inspectors in charge of aircraft to require the separate qualification of welders. This requires the employment of a separate set of welders for each service. This is brought about because the qualification tests, though basically similar, varied in the test specimen required.

Under the emergencies of preparation for all-out war at this time, the unnecessary duplication in qualification has been brought to light, and both procurement agencies usually agree to accept a consolidated test.

The author was instrumental in initiating in the central procurement district a satisfactory consolidated test routine acceptable to both branches of the service. In the following paragraphs will be given a satisfactory consolidated test such as that mentioned, as well as general instructions on fusion welding, both for aluminum and aluminum alloys, along with other metals in general.

The following discussion is best divided into:

1. Qualification tests.
2. Fusion-welding procedure for aluminum and aluminum alloys.
3. Welding procedure, Army and Navy requirements.
4. General notes on fusion welding of metals.

**Qualification Tests.**—This test is in three sections.

1. Qualification tests—aircraft steel.
2. Welding procedure.
  - a. Aluminum and aluminum alloys.
  - b. Corrosion-resistant steel.
3. General notes on welding of metals.

**Qualification for Ferrous Metals.**—The sheet and tube used for the welded sample should be of normalized X-4130 steel. The welding rod should be the same as that used in regular production.

In general, no welder should be permitted to perform welding operations applicable to any Army or Navy contract unless he has been qualified and classified to weld in one or more of the following groups. Evidence of such classification should be filed in his certificate of approval, which should be submitted in triplicate to the following authorities:

1. One copy to be sent to the inspector of naval aircraft.
2. One copy to be sent to the inspector-in-charge of army aircraft.
3. One copy to be sent to the chief engineer or engineering authority concerned.

Welders should be classified to weld in the following groups:

- Group 1. Plain and carbon steel and alloys.
- Group 2. Stainless and corrosion-resistant steel.
- Group 3. Nickel alloys.
- Group 4. Aluminum alloys.
- Group 5. Magnesium alloys.

The detail classification of these welders should be made on a basis such as the following:

*Class A welders* will be those welders who have passed qualification tests for all groups as outlined.

*Class B welders* will be those welders who have passed qualifications for Group 1 alloys. However, only low-stressed accessories and parts that are not members of the primary or secondary structure of this group should be welded by Class B welders.

*Class A special welders* should be those welders who have qualified for any single group and should not be instructed by stress classifications.

An example of a characteristic certificate of coordinated classification may be arranged as follows:

# CERTIFICATE

## COORDINATED WELDING QUALIFICATION ARMY AND NAVY CONTRACT

JOHN DOE MANUFACTURING COMPANY  
ST. LOUIS, MO.

WELDER:.....

...BADGE NO.:

AGE:.....

DATE QUALIFIED:..

FUSION WELDER  
(Oxyacetylene, Oxyhydrogen)  
EXPERIENCE

Training school: 1..  
Plant production: 2..  
Aircraft production: 3..  
Present employer: 4..  
General remarks: 5..

QUALIFICATION TESTS

WELDING TORCH MFR.:.....MODEL No.

JOINT No.

Oxygen pressure  
Acet. pressure  
Tip size

Welding-rod mfr.:.....Size:.....  
Welding-rod coating:.....Analysis of rod:.....  
Trade name of rod:.....Base metal mfr.:.....  
Tensile strength of base metal:.....  
Analysis of base metal:.....  
Welder's signature:.....Date:.....  
Supervisor:.....I.N.A.....A.C. Rep.....

PHYSICAL TEST REPORT  
AFFIDAVIT

REFEREE LABORATORY PHYSICAL TEST REPORT  
FUSION WELDED SAMPLES

To: 1. Chief, Bureau of Aeronautics, Navy Dept., Washington, D. C.  
2. Chief, Materials Division, U.S. Army Air Forces, Wright Field, Dayton, Ohio. We have submitted the following test samples to the physical tests required by U.S. Navy, Bureau of Aeronautics, Specification SR-14; U.S. Army Air Corps Specification 20013, and evidence by this affidavit our results.

Samples submitted by:.....  
Samples submitted are:.....in number and  
are marked as follows:

1. ....	4. ....	7. ....	10. ....	13. ....
2. ....	5. ....	8. ....	11. ....	14. ....
3. ....	6. ....	9. ....	12. ....	15. ....

Our results are

Sample number	Area	Yield-point load	Ultimate load	Y.P. stress, p.s.i.	Ultimate stress, p.s.i.	Elongation, % in 2 in.	Fracture	Macro-structure	Joint number	Type of weld
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										

SIGNED:..

DATE:...

APPROVED (U.S. NAVY):.....

APPROVED ARMY AIR FORCES:.....

### QUALIFICATION-TESTS PROCEDURE

The qualification tests should consist of the manufacture of the four types of test joints, as shown in Fig. 35. The qualification should include *all four* without exception.

**Open Single-vee Butt Weld—Joint 1.**—This weld is made with a single reinforcement. The reinforcement is machined off and the sample cut up into test specimens of the form and dimensions shown on Fig. 35. Not less than three specimens are to be cut from the sample. A tensile test should be made on each specimen. The strength of any individual specimen should not be less than 90 per cent of the average value given in Table 55.

TABLE 55.—TENSILE STRENGTH WELD METAL, POUNDS PER SQUARE INCH

Carbon content of filler rod	Carbon-steel base metal	Alloy-steel base metal
Up to 0.06.....	45,000	55,000
0.07-0.12.....	50,000	65,000
Over 0.12.....	55,000	70,000*

\* These values shall be used for alloy-steel filler rod.

**Tubular Butt Weld—Joint 2.**—This is an open-butt weld and should be made with the tubes in a horizontal position for one specimen and in a vertical position for a second specimen. One set, consisting of a horizontal and a vertical specimen, should be welded on the bench and a similar

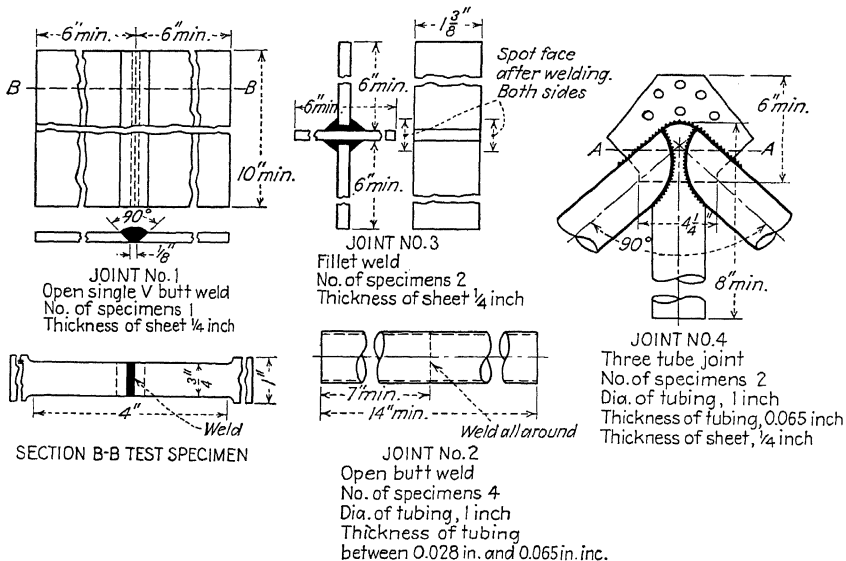


FIG. 35.—Qualification test joints for Army-Navy welders.

set in an overhead position not lower than the welder's eyes. The overhead specimens should not be rotated. The joints should be tested as tensile specimens with the reinforcement. The strength of the joint should not be less than 50,000 p.s.i. for plain carbon steel and 80,000 p.s.i. for alloy steel, calculated on the area of the base metal.

**Vertical Fillet Weld—Joint 3.**—The joint is to be made with the sheet standing on edge. The places are supported so that there is a clearance

between the lower end of the seam and the jig. The joint should be tested in tension as indicated on Fig. 35. The joint should develop not less than 10,000 lb. per linear inch in case the base metal is plain carbon steel and 15,000 lb. per linear inch for alloy steel. The broken specimen should be examined to determine whether or not the weld has been fused into the base metal in the corner.

**Combination Sheet and Tube Fillet Weld—Joint 4.**<sup>1</sup>—This joint is cut at section *AA* and either half polished and etched with 50 per cent aqueous hydrochloric acid at a temperature of approximately 180°F. (82°C.) for a sufficient length of time to bring out the boundaries between the weld metal and the base metal. A visual examination of the section should be made in order to determine the presence of blowholes or porosity in the weld metal and the penetration of the weld metal into the base metal. A penetration between 25 and 40 per cent below the surface of the base metal is desired in the case of material  $\frac{1}{8}$  in. or thicker. The penetration may be greater than this for thinner materials.

**Macro-etching.**—Specimens are prepared for macro-etching by rough grinding or filing until flat, grinding on No. 00 emery cloth or equivalent, and then polishing on No. 0 emery paper. Each grinding or polishing operation should remove the scratches left by the previous operation.

A saturated solution of ammonium persulphate should be used for etching. It may be applied with a small cloth or wad of cotton. When the etching is finished, hold the specimen under running water, and rub with a cloth or cotton. Wash with alcohol or hot water, and dry quickly.

Radiographic X-ray examination may be substituted for "sectioning." Such X-ray negatives, however, must be made a part of the "physical-test report" affidavit and forwarded with the affidavit.

A semiannual reexamination of all welders qualified should be made each 6 months by a retest of a selected-joint specimen.

**Non-ferrous Qualification.**—The basis for non-ferrous qualification will include groups 2, 3, and 5, *viz.*, stainless and corrosion-resistant steel, nickel alloy, and magnesium alloy.

The butt-welded joints in sheets of the chemical compositions to be used in production should be made. One joint should be made between two sheets of equal thickness that represents the thinnest sheet to be welded in production, and one joint should be made between two sheets of equal thickness but should represent the thickest sheet to be welded in production.

The joints must be at least 6 in. long. The characteristics of the weld must be determined by visual examination and bend tests. The weld metal must be of uniform thickness, reasonably smooth of surface, and free from inclusions and irregularities that indicate lack of sufficient

<sup>1</sup> Note design of plate to allow testing of one sample in tension.



experience or skill on the part of the welder. In case of sheets over  $\frac{1}{8}$  in. in thickness, the metal may be laid on both sides of the joint.

Standard bend-test specimens for butt-welded joints should be cut into pieces approximately 1 in. in width. The specimen then should be bent 180 deg. over one sheet thickness so that the outside of the bend will lie in the plane of the weld. The outside of the bend must be on the side on which the weld is laid for joints welded on only one side. The joint must not crack or show indications of lack of bond between the weld metal and the base metal. The excess metal on either side of the sheet may be ground smooth with the base metal before making the bend.

After the welder has passed the tests described, he should be required to weld one aircraft part, such as a fuel tank or an exhaust stack, on which he will weld in production. This part should then be submitted to the Air Forces inspector and inspector of naval aircraft in connection with the qualification test. It may be delivered as an article on the contract, if accepted by the inspectors.

#### **FUSION-WELDING PROCEDURE INSTRUCTIONS FOR ALUMINUM AND ALUMINUM ALLOYS**

There are a number of general notes applicable to the fusion-welding procedure for aluminum and aluminum alloys. These generally apply in all cases and should be observed by both the welder and instructor during the training period and the period devoted to qualification.

**Torch-welding Heat Treatment of Aluminum and Aluminum Alloys.**—Torch-welding heat-treated aluminum and aluminum alloys require considerable more technique than the alloys of the un-heat-treatable type. Every effort should be made to eliminate the overheating of local areas of the establishment of localizing hot spots that lead to flame-hardened areas.

Among the methods that are employed for joining aluminum or its alloys, there is none more generally satisfactory than fusion welding with an oxyhydrogen or oxyacetylene torch. In the hands of an experienced aluminum welder, the process is simple and rapid. It can be applied to metal of all thicknesses. The resultant joint is neat, and, if necessary, the weld can be finished off in such a way that it is practically impossible to detect where the joint exists.

The same types of joints, such as butt, lap, tee, fillet, etc., made in any other metal are also made in aluminum.

Some training will be necessary before a welder can turn out consistently reliable results with aluminum. The metal also has distinct characteristics of its own, which involve a somewhat different technique from that required with steel, cast iron, and other metals. This

technique, how ever, is by no means difficult to acquire, for in point of fact, aluminum is one of the most readily weldable of all metals.

Torch welding is applicable both to the manufacture of articles from wrought aluminum and to the repair of aluminum-alloy castings. Although the differences in physical properties in these two applications and the effects of expansion and contraction involve slight modifications in welding technique, the methods of working are generally the same.

The apparatus required for torch-welding aluminum consists essentially of a supply of oxygen and hydrogen, or oxygen and acetylene, with reducing valves and safety valves, torches, and a series of tips. The oxygen, hydrogen, and acetylene are usually obtained from cylinders of compressed gas, although in some of the larger plants, the gas is piped directly to the benches from a central generating station.

The selection of the correct size of torch for any particular work is largely a matter of experience. The data given in Table 56 may serve as a guide for the inexperienced welder.

In this table, the approximate sizes of tips and the gas pressures to be used in welding aluminum of different thicknesses are given. The size of the tip must largely depend upon the shape and size of the object to be welded, as well as upon its thickness, since the larger articles have a greater capacity for heat and a larger radiating surface. The size of the tip also depends upon the skill of the welder; a quick worker will be able to use a larger tip than a slower and less experienced man.

In welding aluminum and its alloys, an oxyhydrogen flame is often used when it will supply sufficient heat for the job at hand. The oxyhydrogen flame produces a clean and satisfactory joint and usually supplies sufficient heat for welding metal up to  $\frac{1}{4}$  in. in thickness. As indicated in Table 56, a larger tip is used for hydrogen than for acetylene on any given gauge of sheet.

Whether hydrogen or acetylene is used, the torch should be carefully adjusted to show a neutral flame, since this gives the best speed and economy, as well as a cleaner and sounder weld.

The oxyhydrogen flame is neutral when the volumes of the two gases issuing from the tip of the torch are balanced. If there is an excess of oxygen, the flame will be rather small and will have a very short cone at the tip of the torch. With an excess of hydrogen, the flame is long and ragged, and there is no well-defined cone at the center. The neutral flame, in which the mixture of the two gases is properly balanced, has a well-defined jet or blue cone in the center of the large flame.

A wide variety of flame conditions is possible with acetylene by different adjustments of the torch. A neutral flame is secured by reducing the amount of acetylene until only one white cone is visible.

Outside this cone is a nearly colorless flame of large volume. Not only is the neutral flame the hottest but it also prevents excessive oxidation of the molten metals by providing a reducing gas envelope. To readjust the welding flame, it is best to increase the stream of acetylene until two cones appear and then decrease it until only one cone is visible.

TABLE 56.—APPROXIMATE SIZE OF TIPS AND RELATIVE GAS PRESSURES USED IN WELDING ALUMINUM OF DIFFERENT THICKNESSES

Oxyhydrogen				Oxyacetylene		
Metal thickness, B & S gauge	Diameter of orifice in tip, in.	Oxygen pressure, p.s.i.	Hydrogen pressure, p.s.i.	Diameter of orifice in tip, in.	Oxygen pressure, p.s.i.	Acetylene pressure, p.s.i.
24-22	0.035	1	1	0.025	1	1
20-18	0.045	1	1	0.035	1	1
16-14	0.065	2	1	0.055	2	2
12-10	0.075	2	1	0.065	3	3
$\frac{1}{8}$ - $\frac{3}{16}$	0.095	3	2	0.075	4	4
$\frac{1}{4}$	0.105	4	2	0.085	5	5
$\frac{5}{16}$	0.115	4	2	0.085	5	5
$\frac{3}{8}$	0.125	5	3	0.095	6	6
$\frac{5}{8}$	0.150	8	6	0.105	7	7

*Safety Precautions.*—The oxygen, hydrogen, and acetylene are tapped from cylinders or pipe lines through regulating or reducing valves in order to deliver the gases at the proper working pressures and at constant volume. Since the regulator works on the diaphragm principle, the tank valve should be opened only when the regulator diaphragm adjusting screw is fully open. Otherwise the full pressure of the gas would be blown against the diaphragm with such force as to rupture it.

The operator should never use oil or grease of any kind around the oxygen tanks, regulators, valves, or gauges, because oil will ignite and burn violently in the presence of oxygen under pressure. The operator should ascertain also that no oil or grease is on his hands, gloves, or the rags used in handling the welding apparatus.

As a further safety measure, in order to prevent the gauges from becoming accidentally mixed, the connection on the oxygen regulator has right-handed threads, whereas that of the acetylene or hydrogen line has left-handed threads.

*Use of Flux.*—As a natural characteristic, all aluminum is coated with a thin film of aluminum oxide. The production of a sound weld in aluminum necessitates the removal of this oxide film from the welding zone by mechanical means or by solution, as with flux.

Good fluxes are prepared by a number of reputable manufacturers. Aluminum Co. of America markets a flux for torch-dwelling aluminum known as "No. 22 Welding Flux."

A satisfactory way to use the flux is to mix it with water to the consistency of a thin paste (about 2 parts of flux to 1 part of water). A day's supply of the flux paste should be made up each morning. If any is left overnight, it should be broken up and thoroughly stirred the next morning, since it has a tendency to crystallize in a lump when standing. Since aluminum flux absorbs some moisture from the air, the container for the dry flux should be kept tightly closed to prevent spoilage.

The flux paste may be applied to the seam to be welded by means of a brush. If a welding wire or rod is used, the most convenient method is to dip the wire or rod into the flux paste just prior to welding. The coating of flux on the wire is melted by the heat of the torch. It runs down the work and flows along the seam ahead of the torch flame, removing the oxide film and leaving the metal in an absolutely clean condition. Thus the parts readily join.

*Choice of Welding Wire.*—Of utmost importance is the proper selection of the welding wire or rod, since the success of many jobs depends upon the proper material being used.

The nonheat-treatable aluminum alloys Alcoa 2S and 3S should ordinarily be welded with 2S wire, but the nonheat-treatable alloy 52S and the heat-treatable alloys 51S and 53S should ordinarily be welded with a rod consisting of 5 per cent silicon and 95 per cent aluminum (43S alloy).

On jobs where the parts are held tightly in jigs, 43S welding wire should be used, regardless of the composition of the alloy. This is more necessary, however, for the strong alloys, since they are more hot-short than pure aluminum. Alcoa 43S welding wire fuses readily with all aluminum alloys, has good corrosion resistance and high strength. It is satisfactory to use in welding any of the ordinary aluminum alloys.

The 43S welding wire has a relatively slight solidification contraction. Because of its lower melting point and wider melting range, it remains molten or at least soft for a longer time than the base metal and fills in the voids caused by the solidification shrinkage of the welded parts in the same way that a gate fills in the shrinkage of a casting. This welding wire is noteworthy for its freedom from hot shortness. It has fair ductility and strength at temperatures just under the melting point. It will therefore readily stand the strains incidental to welding.

Welding-rod sizes have been standardized at  $\frac{1}{16}$ ,  $\frac{1}{8}$ ,  $\frac{3}{16}$ , and  $\frac{1}{4}$  in. diameter. A rod diameter should be chosen that will approximate the thickness of the material to be welded. Ordinarily,  $\frac{1}{8}$  in. diameter rod is suitable for welding any thickness of metal up to  $\frac{1}{8}$  in.; and  $\frac{3}{16}$  in.

diameter rod is suitable for the heavier gauges. However, this welding rod may be obtained in any gauge to suit individual preference.

*Preheating.*—Aluminum sheet  $\frac{3}{8}$  in. or more in thickness and the larger aluminum castings should be preheated to 700 or 800°F. in order to avoid heat strains and to reduce the amount of oxygen and acetylene required for the actual melting of the seam. If the base metal, for some distance on either side of the seam, is maintained at a temperature slightly below its melting point, then, when the torch is applied, the additional expansion at any one point will be small and unlikely to cause distortion.

It is important that the preheating temperature does not exceed the upper limit of 800°F. If the temperature goes much above this, there is danger of some of the ingredients of the alloy melting and producing "burned" material; then, too, the high temperature may cause large castings to collapse in the preheating furnace. For shops not equipped with pyrometers, three methods are suggested for determining the proper preheating temperature.

1. At the proper temperature for welding, a pine stick rubbed on a casting will leave a char mark.

2. Chalk marks, made with carpenter's blue chalk, will turn white at the proper temperature for welding.

3. When struck, cold aluminum gives a metallic sound, which becomes duller as the temperature is raised. At the temperature required for welding, there is no longer a metallic ring.

As a welder become experienced in handling aluminum, he will at times be able to use a low-temperature oil or gas torch for partial preheating. In this case, the preheating is done locally along the seam, just ahead of the welding flame, so that the welding heat will not bring on too sudden a rise in temperature and cause cracking.

*Cleaning and Finishing Welds.*—As soon as the weld is completed and the work has had time to cool, it should be washed thoroughly to remove all traces of flux. This is particularly true of parts that are to be painted subsequent to welding, since the presence of even minute quantities of flux under a paint coating will lift the coating in a short time. On other parts, residual welding flux on the joint may be corrosive to the metal when exposed to atmospheric moisture. The most satisfactory way of removing the flux is to provide a medium that will dissolve the flux ingredients.

Many parts can be cleaned in boiling water if the joint can be reached so that a brush can be applied to the surface of the weld. For inaccessible welds, such as the inside of tanks, cleaning can be done by immersing the part in a cold solution of 10 per cent sulphuric acid for 30 min., or in a 5 per cent solution of sulphuric acid held at 150°F. for 10 min. The acid should contact both the inside and outside surfaces.

In many instances, the appearance of the weld bead is satisfactory without other finishing than washing. In other cases, it is desirable to remove all traces of welding. This may be readily accomplished by chipping off the greater portion of the excess metal with a pneumatic chisel. The cutting edges of the chisel should frequently be dipped in light oil to prevent aluminum chips from sticking to the chisel. After chipping, the joint should be ground on a rag wheel made up of new clean buffs glued together. Glue is painted over the grinding surface of the wheel and powdered emery (30 to 120 mesh—usually 80 mesh) embedded in the surface of the glue. The wheel, which is 8 to 10 in. in diameter, should have a speed of about 2,400 r.p.m. American red engine oil, or Acopol, and asphalt-base engine oil, mixed with equal parts of mutton tallow, is a good lubricant. If an exceedingly smooth finish is desired, a second wheel coated with 120- to 140-mesh emery should be used. This operation should be followed by buffing. The buffing wheel is made up of sewed rag buffs separated by small pads that fit over the shaft in the same manner as the buffs. Tripoli is commonly used in buffing. Wheels about 12 in. in diameter, revolving at 2,600 r.p.m., are recommended.

It is common practice to finish welds in 2S and 3S alloys by hammering. This process can be recommended particularly on chemical and gasoline equipment requiring a smooth surface as well as maximum strength in the weld area. Hammering is done on the aluminum alloys by first chipping the irregular edges off the weld bead and then beating the bead down over a heavy back-up piece to the same thickness as the metal on each side of the weld. Sufficiently heavy blows should be used to work the weld throughout the cross section and not merely topeen the surface.

This process tends to relieve the contraction strains set up during cooling of the weld and the adjacent metal, as well as to close up any surface porosity that may be present.

#### **TORCH-WELDING HEAT-TREATED ALUMINUM ALLOYS**

Of the heat-treatable alloys, Alcoa 51S and 53S are the most practical to join by torch welding. Extensive use of these two alloys has been made in the aircraft industry.

In general, the technique of handling the torch and adjusting the flame and tip size is practically the same as for the un-heat-treatable alloys. The preparation of the joints by veeing and notching is also similar. Furthermore, a welding flux must be used in the same manner. There are, however, some differences in the following details of the technique.

The best filler rod to use for 51S and 53S alloys is composed of 95 per cent aluminum and 5 per cent silicon, an alloy known as "Alcoa 43S." The melting point of this rod is lower than that of aluminum.

Consequently, when the welding pool freezes, the material solidifies last. Thus the contraction strains, which are sometimes sufficient to cause cracking at the edge of the weld bead, are taken up in a somewhat similar manner to that in which a casting riser provides molten metal to a solidifying casting. The wire diameter should be the same as for welding the nonheat-treatable alloys.

Where the assembly of 51S and 53S alloy parts is done in jigs, it is imperative that the parts are free to expand and contract, for these alloys are more sensitive to cracking adjacent to the weld bead, when cooling, than are the nonheat-treatable alloys. If cracks occur, steps must be taken to prevent the contraction from placing stress on the weld. One expedient is to tack-weld the parts while they are in the jig and then loosen the jig clamps before completing the seam. In other cases, it is sufficient merely to loosen the jig clamps immediately after completing the joint. In general, the further the clamps are placed from the weld the less will be the stress in the weld and hence the greater safety from cracks occurring.

Welding 51S or 53S alloys should be done in one pass. Reheating the metal to lay down a second bead is undesirable, particularly on vessels that are to be water- or gas-tight. Also, welding, in one pass is generally faster and more economical than welding in two passes.

The usual methods of finishing welds, such as grinding or buffing, can be applied to welds in 51S or 53S alloys. Hammering a weld bead until it is flush with the plate surface, as in finishing welds on the nonheat-treatable alloys, cannot generally be done on the heat-treatable alloys. The alloy material in the weld bead and in the transition zone, work-hardens more rapidly than in the case of nonheat-treatable alloys. Therefore, failure by cracking may occur under the hammer. Some hammering, of course, can be done, but the weld bead must first be chipped close to the metal surface if cracks are to be avoided.

To make clear the effect of the welding heat on the heat-treated structure of these alloys and therefore on their strength, it is necessary to describe the metallurgical aspects of the problem. Both 51S and 53S contain alloying constituents added to the aluminum base metal. By bringing these alloys up to a temperature of 970°F. and quenching in cold water, the constituents are so held in solution in the base metal that the mechanical properties are raised considerably. This process is known as the "solution heat treatment," and the material is designated as being in the "W" temper.

By subjecting the material to an additional heat treatment or aging, *viz.*, holding the material at 320°F. for 18 hr., the mechanical properties of these alloys can be raised further. The material is then designated as being in the "T" temper.

When annealed material ("O" temper) is welded, the heat does not lower the mechanical properties, since the cast material in the weld is stronger than the parent alloy.

This is not true of welding in the "W" or "T" tempers, however. The welding heat lowers the strength of the heat-treated parent material in the area near the weld, although the metal is not fully annealed by the welding operation. Some air quenching occurs as the torch moves along the joint and the metal cools. The strength of the joint is therefore more than the strength of annealed material but less than the strength of material in "W" or "T" tempers. The effect that welding has on the strength of structures is generally not predictable. Individual cases usually require testing to determine their strength accurately.

#### WELDING PROCEDURE—ARMY AND NAVY REQUIREMENTS

The welding flame should be held at an angle of approximately 30 to 45 deg. to the plane of the weld. It is desirable that the entire seam should be welded in one continuous operation as rapidly as possible.

The edges to be jointed should be bent up sharply to an amount equal to approximately three times the thickness of the sheet. Apply flux to all surfaces involved in the welding operation as completely as possible. Fasten edges together with clamps or other means, as the case demands. Tack-weld edges as necessary to preserve straightness of the seam. The clamps may now be removed, if desired, and welding operation completed by melting down the flanges and adding welding rod and the flux as needed to effect a sound joint.

A smooth, well-rounded bead should be formed on both sides of the joint. The underside of the joint of sheets jointed in the same plane is similar in appearance to the top side; there should be little or no evidence that the sheet has been flanged prior to welding.

In the event that it is impracticable to complete the welding operation immediately after tack welding, a minimum amount of flux should be used and the flux should not be allowed to remain on the parts. The application of flux to the rod only is usually satisfactory. However, inasmuch as flux is an essential to the welding of aluminum alloys, care must be taken that flux completely cover all surfaces that will be fused during the welding operation.

**Fillet and butt welds** should be made in the conventional manner, with sufficient weld metal being added to provide a suitable fillet or reinforcement. Tack welds may be made where practicable. The parts should be held in place by weights or jigs, so arranged as to allow for expansion and contraction of the metal. Welds should be started away from the edges in order to reduce the possibility of cracking. If materials



of different thicknesses are being joined, care should be taken to avoid burning the thinner material.

**Precautions.**—The use of flux is essential in producing a good weld, but the minimum amount should be used for most satisfactory results.

**Burning.**—Aluminum or aluminum alloys give no indication of approaching their melting points, and care should be taken, therefore, to avoid melting through the metal at the start of the weld. Welding should proceed rapidly but uniformly until the seam is completed.

**Expansion.**—The linear expansion of aluminum is approximately three times that of steel. Preheating and slow cooling, as specified herein, should compensate for this property in welding castings and heavy wrought sections, but flat surface of tanks or other closed containers should be beaded or corrugated to provide for expansion and contraction of the metal.

Castings and heavy wrought sections should be allowed to cool very slowly after completion of the welding operation. Cooling in the preheating furnace is recommended.

**Flux Removal.**—Excess welding flux must be completely and promptly removed after welding, for serious corrosion will occur if the flux is allowed to remain any appreciable length of time on the welded joint. Aluminum and aluminum alloys should be cleaned after welding, except where the weld on castings is on a flat surface and in a readily accessible location, in which case, cleaning by vigorous scrubbing with a stiff bristle brush and hot running water is permissible.

**Heat Treatment.**—Alloys that depend upon heat treatment for their maximum physical properties may be welded, but reheat treatment after welding is necessary if it is desired to retain the maximum properties and corrosion resistance.

#### GENERAL NOTES ON WELDING OF METALS

The following instructive suggestions and recommendations are made for the purpose of offering to the prospective welder information on fusion welding in general for all metals.

**Fusion Welding.**—A weld may be defined as a localized union or consolidation of metals. Although the several welding processes involve other factors in addition to the application of heat, the importance of the effect of heat in all practical welding operations should be recognized.

Welding, as embraced in the scope of this article, is usually employed to unite like metals for purposes in which the union or joint will be called upon to develop strength and transmit stress. The preceding definition is broad enough to include certain subsidiary processes, such as bronze welding and hard facing, which involve unlike melts, although low-temperature soldering will not be covered.

**Fusion Welding Processes (Non-pressure).**—These processes differ from pressure welding in that they depart from the union of plastic metals and utilize fusion of metal upon or between the surfaces of the parts being united, the fused metal being generally obtained by deposit from an external source, although in some instances the abutting edges are merely fused together to form the joint.

**Oxyacetylene Welding.**—Oxyacetylene welding is a form of fusion welding wherein the heat required is supplied by the oxyacetylene flame. Usually, in fusion welding, a filler metal is added in the form of welding rod to form the welded joint, although joints in some instances are formed in oxyacetylene welding merely by fusing together the parts to be joined without the addition of welding rod. As a means of floating out impurities or aiding in obtaining a satisfactory bond, flux is employed in the welding of some metals, such as cast iron, certain alloy steels, and the non-ferrous metals.

In the combustion of acetylene and oxygen, the resulting flame has characteristics that indicate whether it is reducing or oxidizing in character. If the acetylene and oxygen are in proportion, a neutral flame results. In most gas welding, the neutral flame is recommended, but in certain welding applications, a slightly carburizing or slightly oxidizing flame is considered desirable. Certain of the alloy materials are welded to advantage with a slightly reducing or carburizing flame, and under certain conditions a reducing flame is considered desirable in the welding of steel materials.

An important characteristic of the oxyacetylene flame lies in the protection of the molten metal from atmospheric attack by the outer envelope of the flame. The surrounding oxygen at this point is consumed in the final combustion stage of the flame.

#### GENERAL NOTES ON WELDABILITY OF METALS

**Carbon Steels (Low-carbon Steel up to 0.38 Per Cent Carbon).**—These steels are easily welded by gas-welding processes, and the resultant welds and joints are of extremely high quality.

The joint edges should be clean and properly prepared to facilitate good fusion and a sound weld. In welding long seams, allowance must be made for the effect of heat along the line of weld, which causes contraction during cooling and tends to pull the unwelded ends of the plates together. The normal spacing that is allowed in welding is  $\frac{1}{4}$ -in. opening per foot of seam. Faster welding speeds will materially reduce the amount of contraction obtained. In making fillet welds, the overlapping plates should be held close together.

A neutral flame is frequently used in welding steel of this class. Increased welding speeds are possible, however, by using a slightly

reducing flame. This type of flame carburizes the kerf surfaces, thereby lowering their melting temperature and making possible fusion of the deposited metal to the plates at a temperature lower than would normally be required. Welded joints made in this way are of high quality, and the fusion zone is not hard or brittle.

The preference for filler metal at the present time is for the so-called "high-test" welding rods with about 0.15 to 0.20 per cent carbon and certain metallic elements that will ensure freedom from included oxides and give the proper fluidity in the molten metal.

**Medium-carbon Steel (0.30 to 0.50 Per Cent Carbon).**—In welding this material, better welds can be obtained if an excess of acetylene is used in the welding flame. The recommended welding procedure is similar to that for low-carbon steels. As a rule, little trouble is experienced from the formation of hard and brittle constituents as a result of rapid cooling. The quality of the finished joint will be improved if it is heat-treated after welding.

**High-carbon Steels (0.50 to 0.90 Per Cent Carbon).**—Since these steels are often heat-treated, the welding heat will affect such treatment and produce a joint of different properties from those possessed by the original metal. Care should be taken to prevent overheating of the parts, and the weld should be completed as quickly as possible. These materials melt at a lower temperature than the lower carbon steels and tend to spark when overheated, a condition that aids from overheating of the parts.

A carburizing or excess acetylene flame is advantageous in securing strong sound welds. High-carbon filler rods are often used, although satisfactory results can be obtained with medium carbon filler metal, which produces a weld of moderate strength, but the increase in ductility is often beneficial. By heat treating after welding, it is possible to eliminate the effect of the welding heat and to improve the strength of the weld.

**Tool Steels (0.80 to 1.50 Per Cent Carbon).**—These steels are relatively difficult to weld. Drill rods available in the various diameters required for welding and carbon content sufficiently high to cover the carbon range are generally used in welding these steels. The use of a carburizing or excess acetylene-flame adjustment is advantageous in securing sound strong welds. Flux suitable for cast-iron welding should be used sparingly. Preheating and annealing are usually necessary.

**Plain Carbon-steel Castings.**—It is customary to use a general-purpose filler rod for welding these castings, although for the best results, the analysis of the filler metal should be similar to that of the base metal.

**High-manganese-steel Castings.**—In welding these castings, a shallow zone must be heated to a temperature close to 2200°F. and the

filler metal then applied. A rod of the same manganese content as the casting should be used, and if, in addition, the rod contains from 3 to 5 per cent nickel, its use will produce reliable welds. The high nickel content tends to inhibit embrittlement under slow cooling so that no quench is necessary.

**Alloy-steel Castings.**—It is customary to modify the filler rod from the type used in welding carbon-steel castings so that the weld deposit will be similar to that of the alloy castings. The same requirements for fluidity of deposit are necessary as in the case of carbon-steel castings in order that impurities may be brought to the surface in the melting operations.

**Low-alloy, High-tensile Steels.**—Where the strength is of importance, a welding rod of the high-test steel type will give satisfactory results in oxyacetylene welding. Where corrosion resistance is a factor, the welding rod should be of the same composition as the base metal.

**Chromium Alloys.**—Chromium irons may be welded by the oxyacetylene method, provided that adequate precautions are taken, best results being obtained with a practically neutral flame. A slightly reducing flame will result in brittleness of the weld area caused by carbide formation due to affinity of chromium for carbon. A slightly oxidizing flame will result in the formation of chromium oxides, which, being refractory, sometimes result in sufficient penetration of the heat, causing reduced weld strength and slag inclusions.

**Chromium-nickel Alloys.**—This method is generally applied to the lighter gauges. On the thinner sections, a flange-type weld is used and the edges jointed without the addition of welding rod. On gauges where metal must be added, a bare (uncoated) rod is used, with a flux added as a thin paste to the work.

The wider distribution of heat from the acetylene flame, as contrasted with the intense and local effect of the arc methods, makes it desirable to use chill blocks in welding with the gas. Likewise, as a result of the more general heating and expansion of the metal sheet, since stainless steel has a 50 per cent higher coefficient of expansion than carbon steel, it will be found convenient to use jigs and clamps to hold the work.

It is of paramount importance in gas-welding stainless steel to adjust the flame so that it is practically neutral. This will avoid excessive carbon pickup in the metal, which would materially reduce the corrosion resistance of the resultant weld.

**Copper and Copper Alloys (Copper, Touch Pitch, Electrolytic, and Lake).**—These materials can be gas-welded with a sufficiently large flame or by preheating with a charcoal fire or with some form of preheating torch. The work should be insulated for heat conservation as well as for comfort of the welding operator. The backhand method of welding

is preferable for thicknesses greater than  $\frac{1}{4}$  in. If the full strength of the annealed metal is desired, it is necessary to hot-forged the weld or cold-peen and anneal it.

**Deoxidized Copper.**—The procedure for gas-welding this material is much the same as that for the materials of the preceding group. Hot-forging of the weld or cold-hammering, followed by an anneal, will improve the ductility and strength, but the material is generally used in the "as welded" conditions.

**Commercial Bronze, Red Brass, Low Brass, Ounce Metal, and Hydraulic Bronze.**—The procedure for this class of materials is similar to that for the two preceding groups. Where, for artistic purposes, an exact color match is desired, it is usually necessary to use strips of the case metal for filler metal. A strongly oxidizing flame is sometimes used to suppress zinc vaporization. A good brazing flux is always required.

**Brazing, Spring, Admiralty, Commercial, Alpha, and Yellow Brass.**—Although the gas-welding process is considered the most satisfactory method for welding these alloys, the temperature of the gas flame is high enough to render rapid vaporization of the zinc unless care is taken to avoid it either by controlling the heat of the flame in the application or by using a strongly oxidizing flame. Special fluxes are also used for the purpose of covering the molten weld metal with a suitable film to suppress zinc vaporization and obtain sound weld metal.

**Muntz Metal, Tobin Bronze, Naval Brass, Manganese Bronze, and Extruded Brass.**—Oxyacetylene welds in this material are strictly fusion welds, although the heat conductivity of the material is still high, compared with that of steel, so that a large flame is necessary. Zinc vaporization is suppressed by using an oxidizing flame. Where used in the form of architectural bronze, a good color match is obtainable in welding if filler metal strips are cut from the base metal.

**Nickel Silver.**—The oxyacetylene process is well adapted for the welding of this material, particularly in connection with certain lapped connections. Nickel silver-welding rod is given the preference, because it makes a good color match with this material. This material, is largely used in architectural designs and is particularly well adapted for butt or mitered joints. One of the essentials for applying gas welding to this material is that both the base metal and the welding rod must be cleaned and covered with a good brazing flux, and a neutral flame should be used.

**Phosphor Bronze.**—On account of slow cooling and high shrinkage, this process of welding is not so desirable as some of the others. Welds of this process must necessarily be fusion welds if phosphor-bronze welding rods are used, but the base metal need not be fused if the rods are of yellow bronze. The latter do not give a good color match, but

this yellow bronze is the easiest metal to apply without danger of developing hot-short cracks. With either metal, a neutral flame and a good brazing flux are desirable. If a phosphor-bronze rod or cast-bronze rod with a high percentage of tin is to be used, a reasonable degree of preheat is necessary.

**Copper-silicon Alloys.**—With this process, the flame should carry a slight excess of oxygen, which tends to protect the weld metal by an impervious film of the molten silica. It is important that the base metal shall be fused simultaneously with the welding rod in order to avoid incomplete fusion or laps.

**Cupronickel.**—This material can be welded by the gas-welding process, provided that the welding rod has sufficient deoxidizer and a soft flame is used so as to allow quick solidification with minimum agitation. The weld metal will be covered with a silicon film, and the weld should be kept running continuously until completed.

**Aluminum Bronze.**—If the aluminum content does not exceed 5 per cent, the material can be readily welded by the gas-welding process, with the use of a suitable flux. The welding rod must be of correct size so that it will melt only as fast as it is puddled into the weld. For this material, the torch adjustment should be slightly reduced.

**Beryllium Copper.**—Thus far, no flux or gas-fusion welding procedure has been discovered that will eliminate the difficulty arising from the refractory insoluble film of beryllium oxide.

**Aluminum and Aluminum Alloys.**—The commonly used gases for welding aluminum and its alloys are oxyhydrogen and oxyacetylene. Equally good results from the standpoint of soundness, strength, speed, and appearance are obtained with either gas. Standard equipment in the way of torches, hose, and regulators is suitable for welding such materials. Some work has also been accomplished with oxynatural gas and oxypropane derivatives, and although good soundness and strength have been obtained in such welds, the use of these gases does not appear to be economical because of the comparatively low rate of welding.

In fusion-welding aluminum, it is important that a suitable flux be used to remove the oxide coating that forms on the surface of all aluminum alloys in the atmosphere. This oxide coating does not melt at the welding temperatures and will prevent smooth coalescence of the weld metal unless a flux is provided that will melt somewhat below the welding temperatures and that breaks down the surface skin of oxide, permitting the liquid metal from the rod to flow into the molten parent material. A number of good fluxes are available. These are applied either dry or by mixing with tap water to the consistency of a thick paste.

Practically all aluminum-welding fluxes contain chlorides, fluorides, and sulphates. Residual deposits on the joints after welding, and in

the presence of moisture, will attach the base metal. Thorough cleaning is especially necessary on parts that are to be painted, for the presence of flux will lift the paint coatings over the welds. Such action can be prevented by cleaning the parts after welding by scrubbing the joints in boiling water. On tanks or parts where the joints are inaccessible, neutralization of the flux can also be accomplished by dipping for 30 min. in a 10 per cent solution of cold sulphuric acid or by a 10-min. immersion in a 5 per cent solution of sulphuric acid held at 150°F.

The proper choice of filler material for gas and atomic hydrogen welding is important, particularly in joining alloys with comparatively large amounts of alloying constituent. Commercially pure aluminum and metal of higher purity are generally welded with the same grade of metal as the parent material. The same practice is satisfactory for the aluminum-manganese alloys. In welding the aluminum-magnesium alloys or the aluminum-silicon-magnesium alloys, a filler rod containing 95 per cent aluminum and 5 per cent silicon is generally used. This rod has a substantially lower melting point than pure aluminum and permits the dissipation of some of the stress set up by solidification shrinkage and the thermal contraction that occurs in the weld zone as it cools. Cracks in the weld and the transition zone on parts that are welded in jigs to hold proper alignment can be minimized by using this rod.

**Commercially Pure Aluminum.**—This material can be both gas- and arc-welded, and commercial applications have been made on parts ranging in thickness from 0.020 to 1 in. Butt welds are characterized by high ductility in the welds and excellent resistance to impact or shock loading. A strength equal to the tensile strength of the annealed material is obtained in the welds.

Commercially pure aluminum is generally used as a filler material in making welds, and considerable testing and practical use have indicated that the resistance to corrosion of such welds is substantially equal to that of the parent material. Metallic arc welding is generally done with standard flux-coated electrodes containing Al-Si filler rod. However, where maximum resistance to chemical attack is important, a special coated electrode containing commercially pure aluminum filler material should be used.

**Al-Mn Alloy.**—This alloy is widely used where higher strength than can be obtained in welded parts made from commercially pure aluminum is required. The previous remarks on filler wire and resistance to corrosion apply as well to this material.

**Al-Mg-Cr Alloy.**—This material is more sensitive to the application of the welding heat in that cooling cracks, caused by the thermal contraction and solidification shrinkage, may occur when the weld cools. This condition is minimized if a filler material of lower melting point

than the parent material is used, and practically all gas welding is done with an Al-Si filler rod. The preceding condition is not serious when the thickness of the parts is such that welds can be made in one pass. Consequently, most commercial applications have been made on material up to  $\frac{1}{4}$  in. thick. Welded joints in thicker parts will usually require some preliminary trial to determine a method that will cause the least stress in the welds during the cooling period.

The strength of welds in this alloy is generally equal to the strength of the annealed material, but the elongation in the welds is substantially lower than that obtained on commercially pure aluminum or the Al-Mn alloy.

**Al-Si-Mg Alloys.**—All these alloys can be joined with the welding torch. A width in the parent material from two to five times the thickness of the material has been effected by the heat in this method of welding. Reheating after welding will increase the strength of the joint, but because of the cast structure in the weld, a strength equal to the parent material is not obtained. The strength of a gas-welded object of these alloys is usually not predictable, since the annealing effect of the welding heat is dependent on the amount and location of the welds in the parts. Mechanical tests on the welded parts are usually carried out to determine the suitability of the welded assembly for the service intended.

The welding technique is substantially the same as for other materials, and the resistance to corrosion of welded joints is good. Filler wire of Al-Si is usually used.

**Al-Cu-Mg-Mn Alloys.**—Both the strength and resistance to corrosion of welds in these alloys are substantially lowered by gas welding.

**Rolled Nickel.**—This material is readily gas-welded with the use of the oxyacetylene flame. The filler metal should be a bare nickel gas-welding rod made for the gas welding of wrought nickel, with which no flux is used or needed. The oxyacetylene flame should be slightly reducing, with a  $\frac{1}{16}$ -in. excess acetylene feather. The envelope of the flame serves to preheat the unwelded seam (forehand welding), with the welding rod kept within the flame envelope to avoid undue oxidation of the heated end of the rod. It is not necessary to peen the gas weld when it is either hot or cold, since there is no porosity present. Certain types of fabricators still prefer to cold-work welded equipment—a procedure that is not harmful if care is taken to avoid excessive cold work. The deposited metal is extremely ductile and can be cold-worked in later forming operations.

**67 Per Cent Ni-30 Per Cent Cu Alloy.**—The gas welding of this alloy is done with a gas-welding wire of the same composition and a gas-welding and brazing flux designed for this alloy. A slightly reducing



flame is required, as with nickel, and under this flame, the weld metal is very fluid. Position welding is regularly done on pipe lines. The pool of molten metal is not to be puddled or boiled, for this may introduce harmful oxides, which, in turn, may embrittle the weld.

**79 Per Cent Ni-13 Per Cent Cr-16 Per Cent Fe Alloy.**—A welding rod of the same composition as the material being welded should be used. Since the oxides of chromium are refractory and tend to interfere with gas welding if not fluxed away, a flux suitable for chromium-bearing nickel alloys will be found useful. Sound, ductile welds are easily made with a moderately reducing oxyacetylene flame and appropriate welding rod and flux.

**Ni-Cu-Al Alloy.**—The use of a special flux applied in the form of a water paste is required to produce sound gas welds. The heated end of the filler rod of the same alloy must be kept within the protecting envelope of the oxyacetylene flame to prevent oxidation of the aluminum constituent of the rod. A strongly reducing flame is required.

**Magnesium and Alloys.**—The oxyacetylene flame offers a protection to the molten metal through the formation of a protective atmosphere. Welding magnesium alloys with the oxyhydrogen flame requires considerable more skill and is therefore not recommended. The procedure, so far as the manipulation of the flame is concerned, is similar to that employed for aluminum and other metals. It has frequently been found that magnesium parts can be welded more rapidly than aluminum because of their lower heat capacity. Holding the flame sideways at an angle of 30 to 45 deg. to the work will produce the best results. In welding thin sheet, this angle should not exceed about 30 deg. to keep the flame from burning holes in the sheet.

The welding rod should, in general, be of the approximate composition of the work to be welded. The size of the welding rod should bear a relation to the thickness of sections for which they are to be used as follows:  $\frac{1}{8}$ -in. rod should be used for thicknesses up to 0.060 in.;  $\frac{3}{16}$ -in. rod for thicknesses from 0.050 to 0.110 in.;  $\frac{1}{4}$ -in. rod for thicknesses from 0.100 to 0.220 in.; and  $\frac{5}{16}$ -in. rod for thicknesses of 0.200 in. and over.

After welding, traces of welding flux should be carefully removed from the unused portion of the welding rod. Strips cut from sheet may be used instead of welding rod if no rod is available. Welded seams made with strip, however, are less uniform than seams made with rod.

A special welding flux supplied by the producers of the alloys is advisable for welding magnesium. The flux is applied to the welding rod and to the parts to be welded. Since the welding flux must be completely removed after welding, only butt welding is permissible. Lap welds or any type of weld that may produce pockets or corners where flux might become entrapped must be avoided.

The pieces to be welded must first be carefully fitted. Oil or grease should be removed from the areas to be welded with naphtha, gasoline, carbon tetrachloride, or hot alkaline cleaners. The edges of sheet to be welded and the adjacent part of the sheet surface (about  $\frac{3}{4}$  in. wide) should then be carefully cleaned and brightened by wire brushing, filing, or scraping.

The joints to be welded require different preparation, depending on sheet thickness. Sheet of thin gauges (up to 0.040 in.) is flanged about  $\frac{1}{8}$  in., and the flange is welded down into a plain butt. For heavier gauges, from 0.125 in. and greater, it is advisable to notch the edges with a cold chisel to facilitate penetration of the weld. The notches should be about  $\frac{1}{16}$  in. deep and  $\frac{3}{16}$  in. apart.

Castings or extrusions can be welded to sheet if their section is reduced by filing to the approximate thickness of the sheet to which they are to be joined. Sections of slightly different thickness may at times be welded to each other if the heavier section is preheated, so that both edges of the seam will begin to melt and flow at the same time. Rivets of aluminum alloys, when used in magnesium construction, must not be welded over, since this results in a brittle alloy of uncertain composition.

**Welding Procedure.**—After the pieces to be welded have been fitted and cleaned, they should be preheated with the torch to about 500 to 600°F. and the flux applied to the sheet edges and to the rod. The seams should next be tacked at intervals of from  $\frac{1}{2}$  to  $1\frac{1}{2}$  in., depending on the type of work. A distance of 1 to 2 in. is then completely welded on each end of the weld in order to minimize warping in the subsequent welding of the seam. Any sheet that tends to warp during tacking should then be straightened out with a wooden hammer while it is hot. After reheating the sheet and covering the tacked spots with flux, the entire seam should be completed and the sheet again straightened with a wooden hammer. In order to obtain a smooth weld, it is desirable to keep the welding wire in the molten pool of metal and not remove it any oftener than necessary. To accomplish this, sufficient flux should be applied to the work and to the welding wire before welding so as to avoid the necessity of frequently renewing the flux on the welding wire. If any portions of the weld should begin to oxidize, the work must be stopped and the oxidized portion carefully scraped or filed out.

#### WELD CLEANING

After welding (see also Chap. XIII) the flux must be carefully removed with hot water and a wire brush. The welded part should then be given the chromium pickel or dichromating treatment. This treatment is applied by dipping for about 1 min. in a solution made according to the following formula:

Sodium dichromate ( $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$ ).....	1.5 lb.
Concentrated nitric acid (specific gravity = 1.42).....	1.5 pt.
Water.....	To make 1 gal.

The welded article is then allowed to drain, is rinsed in cold running water, and is placed for at least 2 hr. in a container with hot water containing about 0.5 per cent sodium dichromate. Finally, the part should be carefully dried, preferably with a heated air blast. Lacquering of the completed seam is an excellent precaution and ensures stability.

## CHAPTER XIX

### GENERAL NOTES ON AIRCRAFT SOFT SOLDERING

The soft soldering of aircraft parts is governed very closely by existing applicable specifications issued by both branches of the service. Although the technique of soldering remains much the same as standard practices, the materials involved differ in their composition and points of application. Current issues of Army and Navy specifications should be referred to at all times and satisfactory shop methods derived from their instruction. For general application, however, of solder to aircraft parts, the following information will be found acceptable.

The first step in the soft-soldering of a part is the preparation of the surface. The area to be soldered should be cleaned by one of the five following methods:

1. Pickling.
2. Polishing.
3. Filing.
4. Sandpapering.
5. Wire brushing.

In tinning parts, overheating of the solder in the pot should be avoided at all times. In cases where excess scum forms on the top of the pot, the temperature of the tinning pot should be reduced, inasmuch as this indicates excess heat. Ordinarily 50-50 solder starts to melt at 360°F. and is completed liquid at 415°F. The solder in the tinning pot should be kept free from contamination.

The part to be tinned should be immersed in the flux recommended and then into the molten solder. Care should be taken that examination of the part tinned reveals complete coverage. It will be found that by slowly turning the part in the molten solder excess material will not adhere to the part. The part should then be dipped into the flux to ensure a clean tinning coat. Parts treated as recommended should then be neutralized.

For sweating operations the parts properly tinned and fluxed should be assembled in the proper assembly pattern and then heated slowly and evenly to the point at which the solder melts and flows to form the joint. Parts should be neutralized after sweating. The neutralizing operations, as referred to, may be found in Chap. XIV, where the use of soda ash and water is recommended.

The following tables exhibit the activity of approved fluxes or metals during the soldering operations.

TABLE 57.—ACTIVITY OF APPROVED FLUXES ON METALS DURING THE SOLDERING OPERATION

Metal	Spears	S50X	X50	Nokorode	Rosin core
Monel.....	1*	2	3	4	5
Inconel.....	1	3	2	4	5
Copper.....	1	1	1	1	1
Brass.....	1	1	1	1	1
18-8.....	1	3	2	4	5
SAE X4130.....	1	3	2	4	5

\* 1 = very active; 2 = active; 3 = medium; 4 = weak; 5 = non-active.

TABLE 58.—CORROSIVE ACTIVITY OF FLUXES ON METALS AFTER SOLDERING (IF NOT THOROUGHLY REMOVED)

Metal	Spears	S50X	X50	Nokorode	Rosin core
Monel.....	1*	2	3	5	4
Inconel.....	1	2	3	4	5
Copper.....	2	4	3	1	5
Brass.....	1	3	2	4	5
18-8.....	1	2	3	4	5
SAE X4130.....	1	2	4	3	5

\* 1 = very severe; 2 = severe; 3 = medium; 4 = weak; 5 = activity not noticeable.

In the cases of the soft-soldering of fittings and ferrules to flexible conduit, the following steps are suggested:

1. *Fluxing and Tinning*.—Dip the end of the conduit into the following solution:

8 oz. weight.....	Powdered rosin
16 oz. liquid.....	Denatured alcohol

Tin the part end then by dipping in a solder pot of 50-50 solder.

2. *Cutting and Burring*.—Clamp the soldered end of the conduit between split blocks with a bore slightly less than the outside diameter of the conduit in a vise. Cut the end off square with a hack saw through the tinned area, and clean the burr with a file.

3. *Attaching*.—Slip the ferrule or fitting over a rod clamped horizontally in the vise; slip the conduit over the rod down into the ferrule or fitting. Apply rosin-core solder with iron while the conduit is rotated. Complete the joint.

Excess solder may be wiped off with felt and excess flux removed with alcohol and a rag.

The use of acid-core solder on Army and Navy work is strictly prohibited unless specifically allowed by the proper deviation.

## CHAPTER XX

### HEAT TREATMENT OF ALUMINUM ALLOYS

On the basis of Alfred Wilm's work in Germany with duralumin, which was more or less characterized by a common composition of approximately 4 per cent copper, 0.5 per cent magnesium, and 0.5 per cent manganese, the theory of heat treatment for aluminum alloy was enlarged and definitely established without metallurgical basis until the work of P. D. Merica, in a U.S. Bureau of Standard's *Scientific Paper* 347, Nov. 15, 1919, proposed the theory that the underlying basis of age hardening was due to a precipitate of  $\text{Cu-Al}_2$  obtained from a super-saturated solid solution.

Wilm's work, based on the characteristic alloy given above, produced new factors in the metallurgy of non-ferrous metals predicated on hot- and cold-rolling results where tensile strength increased considerably without excessive loss of elongation. This work also encompassed annealing operations that reduced the tensile and lengthened the elongation and finally resulted in the heat treatment of the hot- or cold-rolled material to temperatures above  $500^\circ\text{F}$ ., followed by a quick quench in cold water yielding a metal whose tensile exceeded that of the hot- or cold-rolled material and equaled the elongation of the annealed product. The age-hardening factor upon which Merica predicated his theory of the formation of  $\text{Cu-Al}_2$  precipitated was found to change the elongation very little. The workability or the ability to form and distort, however, decreased without age hardening of the heat-treated product.

At the present time, the ability of aluminum to form solid solutions is well known. It is also well known that the very basis for heat-treatment possibilities is greatly dependent in not only on the forming of solid solutions but on the concentration decrease with temperature as well. By the variation in temperature, the control of concentration is accomplished.

As will be noted from the chemical formula of the precipitate responsible for the increase of tensile properties on age hardening, copper is the underlying alloying chemical factor. By Merica's work, it was proved that when a sufficient amount of copper is in combination to saturate the solid solution at the burning point, the amount of copper taken into the solution during solution heat treatment increases with the temperature of the treatment. Therefore, the greater the amount of copper in combination, the greater the amount of  $\text{Cu-Al}_2$  formed. R. S. Archer, in "The Hardening of Metals by Dispersed Constituents Precipitated

from Solid Solutions," in a paper given before the American Society of Steel Treating, 1926, showed that dispersion hardening was as applicable to ferrous metals as it was to non-ferrous.

The ability of aluminum alloy to be deformed by cold working is greatly dependent upon its ability to distribute the resultant grain growth brought about by such deformation. When an aluminum alloy has been cold-worked to any great extent, the large "grain-growth" structure will appear on the surface of the metal. This is decidedly shown in the present methods of press-working aluminum alloys in mechanical presses by the use of steel dies where deep-drawing operations are required. The refinement of this "grain growth" may be accomplished by annealing and subsequent heat treatment.

Excessive "grain growth" due to cold working should be avoided at all times, particularly where the parts under consideration are to be classed as primary structural parts.

The great advance, as explained in a previous chapter, in the use of aluminum alloys in the aircraft industry has been definitely due to the development of heat-treatable alloys possessing sufficient tensile strength to guarantee their support as strength members. Much research has been devoted to the development of heat-treating technique by both the Army and Navy technical forces. Much time has been given to arriving at the proper temperature and soaking periods for the various heat-treatable alloys. The requirements for both the Army and Navy specifications are more or less the same. The detail heat treatment for applicable heat-treatable alloys are given in the following recommendations. The recommendations given for 2S, 3S, 4S, and 52S are for annealing only, inasmuch as these alloys are of the nonheat-treatable type.

#### 17S (Sheet).

Annealing (partial).

1. Heat to 640 to 660°F. for about 2 hr.
2. Cool in air or furnace to room temperature.
3. Completely remove salts by rinsing.

Annealing (full).

1. Heat to 750 to 800°F. for about 2 hr.
2. Cool in furnace at rate not to exceed 50° per hour.
3. When 450°F. is reached, material may be cooled in air to room temperature.
4. Completely remove salts by rinsing.

Hardening (solution treatment).

1. Heat to 925 to 950°F. (see Table 60).
2. Quench in cold water (less than room temperature).
3. Completely remove salts by rinsing.

#### Alclad 17S (Sheet).

Annealing (partial)—same as for 17S.

Annealing (full)—not permitted.

Hardening (solution treatment). Same as for 17S except for soaking period (see Table 59).

**24S (Sheet).**

Annealing (partial)—same as for 17S.

Annealing (full)—same as for 17S.

Hardening (solution treatment).

1. Heat to 915 to 930°F. (see Table 60).
2. Quench in cold water (less than room temperature).
3. Completely remove salts by rinsing.

**Alclad 24S (Sheet).**

Annealing (partial)—same as for 24S.

Annealing (full)—not permitted.

Hardening (solution treatment)—same for 24S except for soaking period (see Table 59).

**17S Rivets.**

Hardening (solution treatment).

1. Charge into furnace in small screen-wire basket or similar container.
2. Heat to 925 to 950°F., and soak for not less than 30 min.
3. Quench in cold water in such a manner that the water is allowed free and rapid circulation around the rivets.
4. Completely remove salts by rinsing in cold water.
5. Rivets shall be driven within 1 hr. after quenching unless aging is retarded by keeping at a temperature below 32°F.

**2S and 52S (All Forms).**

Annealing. Put into furnace at 625 to 700°F. Thoroughly heat part. Hold 15 min., remove, and cool in air. Cooling in water will not impair softness but will cause distortion. Use method for 61S as optional in emergency.

**3S and 4S (All Forms).**

Annealing. Same as 2S and 52S except that temperature shall be 725 to 775°F. Use same optional method.

**61S-53S and 51S (All Forms).**

Partial annealing. Put in furnace at 600 to 650°F. Bring up heat; hold 15 min. Remove, and allow to cool to room temperature. As emergency, place parts in salt bath at 920°F. long enough to heat part thoroughly. Remove, and cool at room temperature.

**61SW.** Heat in salt bath at 960 to 980°F. for 20 min.; quench quickly in water.

**61ST.** Heat SW for 10 hr. at 350°F. or 18 hr. at 320°F. Cool to room temperature.

The soaking period for hardening is arrived at from the time that the entire charge reaches the desired temperature until it is quenched. The time required to bring the charge to the desired temperature will vary, of course, with the ability of the furnace to accomplish its task. In such cases where a furnace charge is composed of various thicknesses of stock, the soaking time should be determined from the thickest piece. In the quenching of aluminum alloys, the shortest interval possible from furnace to quench medium should be taken. If water quench is used, the volume of the water should be sufficient so that the entire quench bath will not exceed 150°F. when used for quenching a complete furnace charge. When heat-treatable alloys are deformed from their stamped shape during heat-treating operations, it will be found necessary to place the quenched material in an atmosphere not more than 32°F.



in order to retain a state soft enough for straightening or die-striking operations.

TABLE 59.—SOAKING PERIODS FOR HARDENING OF ALCLAD 17S AND ALCLAD 24S

Thickness of sheet, in.	Minimum soaking time for all alloys, min.	Maximum soaking time for Alclad 17S and Alclad 24S, min.	Minimum soaking time for all alloys, min.	Maximum soaking time for Alclad 17S and Alclad 24S, min.
Up to 0.020	5	15	5	15
0.021-0.032	10	20	10	20
0.033-0.063	20	30	15	25
0.064-0.125	30	40	20	30
0.126-0.250	50	70	20	30
0.251-0.500	90	110	30	40

Some common definitions for heat-treating terms are given.

**Solution Heat Treatment.**—The solution heat treatment, heating pertaining specifically to aluminum alloys, consists in heating to a specified high temperature below the melting point, holding at this temperature (soaking) for the correct length of time, and then quenching. In the wrought aluminum alloys, the alloying constituents that provide the higher strengths and hardness are substances that are more soluble in solid aluminum at high temperature than at low temperatures. The purpose of this treatment, therefore, is to put as much as possible of the alloying constituents into solid solution, then to retain this condition by quenching.

**Re-heat Treatment.**—The treatment of material that has been previously heat-treated shall be considered as reheat treatment. Accordingly, the first heat treatment by the fabricator of material purchased in the heat-treated condition shall be considered as reheat treatment.

**Quenching.**—Quenching consists of rapid cooling from the solution temperature by immediate immersion in cold water or other suitable quenching medium.

**Aging.**—Immediately after quenching, the 17S and 24S alloys are relatively soft but are susceptible to hardening and increase in strength by the process of natural aging. Natural aging occurs spontaneously at room temperature immediately after quenching and continues, first rapidly, then at a diminishing rate, so that in 24 hr. the properties are within a few per cent of the fully aged values; the aging is considered to be practically complete in about 4 days.

**Soaking.**—Soaking is defined as holding the material at the temperature specified for either heat treating or annealing for a specified time.

**Annealing.**—Annealing for relief of hardness caused by cold working consists of heating to a specified temperature just above the recrystallization temperature, followed by cooling.

Annealing for relief of hardness caused by heat treatment consists of heating to a specified temperature somewhat higher than annealing for relief of cold-work soaking at this temperature for a specified time, followed by very slow cooling to a temperature below the annealing range.

**Initial Temperature.**—The temperature of the furnace or bath at the time the parts are inserted shall be the same as the heat-treating temperature.

**Heat-treating Temperature.**—The heat-treating temperature is shown in Table 60. If the upper limits exceed, the alloys may be damaged by incipient melting of the eutectic, and if the lower limit is not reached, the minimum required properties of the alloys may not be developed.

#### TREATING MEDIUMS FOR ALUMINUM ALLOYS

The solution method involves the use of sodium or potassium nitrate salts or, most commonly, a 50-50 mixture of both and by air. Heat treating by solution or air varies little except that the necessity of rinsing residual salts does not arise.

Further information on applicable average heat-treating temperatures is given in the following table:

TABLE 60.—HEAT-TREATING TEMPERATURES	
Alloys	Temperature
17 and A17	930-950°F. (498.5-509.6°C.)
24 and A24	910-930°F. (487.5-498.5°C.)

**Soaking Periods.**—In general, the optimum soaking period for any alloy will depend on the type of heating medium, the type of alloy, the prior thermal or mechanical treatment to which the alloy has been subjected, and the size and shape of the part or parts being treated. The recommended periods for soaking material in the heat-treated temper (reheat treatment of material in Condition T) and for soaking material in the soft (annealed) condition (heat treatment of material in Condition A) are shown in Table 61.

Characteristic soaking periods for solution heat treatment in nitrate salts are shown in Table 61.

Soaking periods in air furnaces provided with air circulation are shown in Table 62.

The times shown are measured from the time the temperature of the charge has been raised to the specified heat-treating temperature. It is to be understood that these soaking periods are approximate only, subject

to adjustments as necessary to allow for different types of equipment and classes of work. When a charge includes parts of various thicknesses, whether in an assembly, in separate pieces, or as overlapping member, the entire charge shall be soaked continuously for the period required for the greatest thickness. Alloys 17 and 24 may be soaked without harmful effect in salt baths for considerably longer periods than

TABLE 61.—SOAKING PERIODS FOR SOLUTION HEAT TREATMENT IN NITRATE

Nominal thickness, in.	Time for holding (soaking) after bath temperature has returned to specified value			
	Alloy 17		Alloy 24	
	Condition A, min.	Condition T, min.	Condition A	Condition T
Up to $\frac{1}{16}$	15	5	30	10
Over $\frac{1}{16}$ — $\frac{1}{8}$	20	5	30	15
Over $\frac{1}{8}$ — $\frac{1}{4}$	30	10	45	20
Over $\frac{1}{4}$ — $\frac{1}{2}$	45	10	60	30
Over $\frac{1}{2}$	60	20	60	30

TABLE 62.—SOAKING PERIOD IN AIR FURNACES

Nominal thickness, in.	Treatment			
	Alloy 17		Alloy 24	
	Condition A, min.	Condition T, min.	Condition A, min.	Condition T, min.
Up to $\frac{1}{32}$	20	10	30	15
Over $\frac{1}{32}$ — $\frac{1}{16}$	25	10	40	15
Over $\frac{1}{16}$ — $\frac{1}{8}$	30	15	45	20
Over $\frac{1}{8}$ — $\frac{1}{4}$	45	20	60	30
Over $\frac{1}{4}$ — $\frac{1}{2}$	60	30	90	45
Over $\frac{1}{2}$	90	45	120	45

those specified. In the case of alloys A17 and A24, however, prolonged heating will cause diffusion of the alloying constituents of the core into the pure-metal coating, with consequent impairment of the corrosion resistance. The heating and soaking periods of those latter alloys should therefore be restricted to the minimum that is necessary to produce the required properties. This minimum time should be determined for the particular equipment and class of work involved. The time required for all parts of the charge to reach the specified heat-treating temperature

will vary with the size of the charge and the heating capacity of the salt bath or air furnace. Longer heating-up periods will be required for air furnaces because of the slower rate of heat transfer in air as compared with molten salt. In the case of large loads, the temperature in the center of the load may lag behind the indicated temperature, and it is therefore preferable to time the soaking period from the time a thermocouple placed in the load comes up to the specified temperature. Salt baths are especially preferred to air furnaces for heat treatment of A17 and A24 alloys because of the shorter period required for heating.

The charging of the furnace both as related to the amount and the method is of detail importance. Characteristic recommended instructions may be given as follows:

**Size of Charge.**—The size of charge should be regulated to avoid undue cooling of the salt bath or furnace when the charge is introduced.

**Arrangement of Charge.**—Except as noted herein, parts should not be nested. A space should be maintained between adjacent parts to permit free circulation of molten salt or heated air.

1. In charges composed of multiple small parts, such as spacers, washers, etc., contact between parts is permissible. When a salt bath is used for this class of work, it is recommended that direct contact with the molten salt be avoided by heating the parts in a capped metal cylinder suspended in the bath and quenching the parts by emptying from the cylinder into a perforated or wire container in the quenching water. The cylinder in which the parts are heated must never be quenched.

2. For air furnaces, the thickness differential between separate parts composing the total charge should be restricted so that the soaking time required for the greatest thickness will not exceed four times the minimum time specified for the smallest thickness.

3. In general, charges of A17 and A24 alloys involving different thicknesses of material should be avoided as much as possible because of the danger of excessive diffusion in the coating of the thinner parts.

**Quenching.**—All parts must be quenched from the heat-treating temperatures by immediate immersion in cold water. Parts on trays or containers must be dropped into the quenching medium. The time consumed in transferring the heated parts from the salt-bath furnace must be as short as possible in all cases. Any delay whatever is detrimental to the effectiveness of heat treatment. Prompt quenching is particularly important in the case of alloy 24, since the loss in corrosion resistance occasioned by slow quenching is greater than in the case of alloy 17. The quenching operation should be systematized in such a manner as to eliminate delays due to the lack of coordination and to assure uniform consumption for all loads.

**Washing Parts Treated in Salt Baths.**—Parts that have been treated in nitrate salt baths must be thoroughly washed to remove all traces of adhering salt. Any salt allowed to remain on the surface of parts will hasten corrosion because of its tendency to absorb moisture. If rinsing in cold quenching water will not remove the salt, parts may be thoroughly washed in warm (not hot) water. Since hot water (over 150°F.) will accelerate hardening, it should not be used for this purpose, especially when the alloy is intended to be formed.

**Aging.**—Heat-treated parts of alloys 17 and 24 are considered to have developed their maximum physical properties after 4 days of natural aging at room temperature. Aging of these alloys shall not be accelerated by additional heating of any kind.

The necessity at times arises for the reheat treatment of various parts and for this purpose definite recommendations must be observed. Alloys 17 and 24 may be reheat-treated in salt baths repeatedly without injury, provided that the treatment is carefully and properly performed.

In the case of aluminum-coated alloys (A17 and A24), the heating time shall not exceed the times shown in the table below. With proper loading and spacing, even shorter times will usually develop the required properties.

For reheat treatment in air furnaces, alloys 17 and 24 may be reheat-treated repeatedly with proper atmospheric control, provided that the material is anodized. Material may be reheat-treated once without anodizing.

Alloys A17 and A24 may be reheat-treated in air furnaces for not more than the number of times shown below:

Thickness, In.	Reheat Treatment in Air Furnaces
Up to 0.049	No reheat treatment
0.050-0.077	1 time
0.078-0.125	2 times

The heat-treated (or reheat-treated) test samples will exhibit tensile strength, yield strength, and elongation properties not less than the minimum properties specified in the applicable material specifications, issued by the procurement agency.

The medium and method for quenching, as well as the method of heat treating, greatly influences the corrosion characteristics of some alloys. Government requirements are strict in regard to this situation, and the instructions are that the heat-treated sample for corrosion test shall be approximately 1 × 6 in. and be of suitable thickness to represent the work.

The heat-treated sample must be cleaned by washing first in carbon tetrachloride, then in alcohol. The sample is then dried and corroded by immersion in at least 250 ml. of a solution of the following composition:

Sodium chloride.....	57 g.
3% hydrogen peroxide solution.....	100 ml.
Distilled water.....	900 ml.

This solution must be discarded after 24 hr. and replaced with fresh materials. The time of immersion shall be as follows:

Thickness, In.	Time of Immersion, Hr.
Up to 0.015.....	16
0.016-0.040.....	20
0.041-0.064.....	22
Over 0.064.....	24

At the end of the immersion period, the sample is then removed from the solution and dried. The examination for type of attachment should then be made as follows:

Cut several small cross-section specimens from the sample, and mount them for microscopic examination in company with a blank uncorroded specimen (or specimens) taken from the same heat-treated sample.

Etch the mounted specimens, both corroded and uncorroded, for 6 to 20 sec. in a solution of the following compositions:

Nitric acid, Con. C.P.....	2.5 ml.
Hydrochloric acid, Con. C.P.....	1.5 ml.
Hydrofluoric acid, Con. C.P.....	1.0 ml.
Distilled water, Con. C.P.....	95.0 ml.

Examine at not less than 500 diameters magnification, using a metal-lurgical microscope.

Presence of intergranular oxidation in the blank uncorroded specimen is evidence of improper furnace atmosphere. Presence of intergranular attack in the corroded specimens is evidence of slow quenching. Presence of only pitting attack in the corroded specimens is indicative of proper heat-treating procedure, provided that the grain contrast is also quite marked.

**Hardness.**—Hardness tests as applied to the 17 and 24 alloys are of value chiefly as a means of distinguishing between cold-worked or heat-treated material and annealed material. Hardness tests, when properly conducted, may also be accepted as an indication of the strength developed by heat treating. Hardness tests alone, however, cannot be relied upon as a complete check on the suitability of the heat-treating process, since these tests provide inadequate information on such important factors as yield, strength, and elongation. Hardness tests should be performed by the contractor in the presence of or under the instructions of the inspector.

**Rockwell Hardness Values.**—The minimum Rockwell hardness values shown in Table 63 and Table 64 are representative of the data obtained from tests on various thicknesses of sheet heat-treated and aged for 24 hr. Somewhat higher values may be expected after 4 days' aging. Where blank spaces are shown in the tables, it is considered that the particular combination of load and penetrator does not give reliable results on the

TABLE 63.—MINIMUM ROCKWELL HARDNESS VALUES AFTER 24-HR. AGING FOR HEAT-TREATED ALUMINUM ALLOY 17

Gauge, in.	Penetrator diameter (dial scale used; load in kg.)				
	100 kg. $\frac{1}{16}$ -in. ball; read on red scale	60 kg. $\frac{1}{16}$ -in. ball; read on red scale	100 kg. $\frac{1}{8}$ -in. ball; read on red scale	60 kg. $\frac{1}{8}$ -in. ball; read on red scale	100 kg. $\frac{1}{4}$ -in. ball; read on red scale
0.024 and under	—	—	—	—	108
0.027–0.034	—	—	—	105	108
0.035–0.045	—	—	90	105	108
0.046–0.064	—	88	90	105	109
0.065 and over	60	90	90	105	110

TABLE 64.—MINIMUM ROCKWELL HARDNESS VALUES AFTER 24-HR. AGING FOR HEAT-TREATED ALUMINUM ALLOY 24

Gauge, in.	Penetrator diameter (dial scale used; load in kg.)							
	100 kg. $\frac{1}{16}$ -in. ball; read on red scale	60 kg. $\frac{1}{16}$ -in. ball; read on red scale	100 kg. $\frac{1}{8}$ -in. ball; read on red scale	60 kg. $\frac{1}{8}$ -in. ball; read on red scale	100 kg. $\frac{1}{4}$ -in. ball; read on red scale	45T	30T	15T
0.024 and over	—	—	—	—	100	—	—	81
0.027–0.034	—	—	—	108	108	—	—	81
0.035–0.045	—	—	94	109	108	—	59	81
0.046–0.064	—	95	95	109	109	—	59	81
0.065 and over	68	95	95	109	109	41	62	82

thickness of material indicated. The values shown are indicative of the results to be expected from properly heat-treated material where the size of the piece is such that characteristic readings can be obtained. Heat-treated material that shows hardness values less than those shown herein are considered deficient in strength unless tension-test data indicate satisfactory properties.

**Brinell Hardness Values.**—The normal range of Brinell hardness for heat-treated alloys aged for 4 days is shown in Table 65 for the purpose of information only.

TABLE 65.—NORMAL BRINELL HARDNESS WITH 500-KG. LOAD AND 5-MM. BALL

Alloy	Hardness
17	90–105
24	100–120

Smaller loads will be necessary to obtain satisfactory readings on thin material. The following combinations of load and ball diameter give comparable readings:

Ball Diameter	Load, Kg
10 mm.	500
5 mm.	125
2 mm.	20
1 mm.	5
$\frac{9}{16}$ in.	1000
$\frac{1}{8}$ in.	50
$\frac{1}{16}$ in.	12.61

By the same token, there are annealing instructions exercised by both branches of the service. Alloys A17 and A24 should not be fully annealed for relief of hardness caused by previous heat treatment. If this material is required in the annealed condition, it must be purchased annealed.

The purpose of the annealing procedures specified herein is to increase the formability of the alloys as an aid in fabrication. Annealing is not a final heat treatment. All parts that have been annealed must be heat-treated prior to acceptance for service.

The equipment for annealing, including temperature-control devices, must be of the same type as for the solution heat treatment. Annealing may be done either in an air furnace or in a salt bath.

**Annealing Procedure.**—The annealing procedure to be followed, in any case, will depend upon prior treatment of the material and the degree of softness desired. Annealing may be used for relief of hardness caused by cold-working of material not previously heat-treated or for relief of hardness caused by prior heat treatment. The degree of anneal desired may be either partial or full.

**Full Anneal for Relief of Hardness Caused by Cold Work (Material Not Previously Heat-treated).**—Heat to uniform temperature within the range 640 to 670°F. (338 to 354°C.). Cool slowly in air. Higher temperatures should be avoided, since they produce an effect similar to heat treatment, although to a lesser degree, and the alloy will harden somewhat by aging. Quenching in water involves danger of warping or distortion.



**Partial Anneal for Relief of Hardness Caused by Previous Heat Treatment.**—Use the same treatment as for the full anneal relief of hardness caused by cold work, described above, or heat to a uniform temperature within range 750 to 800°F. (399 to 427°C.), and quench in air or cold water. Either one of these treatments will render this class of material suitable for all but the more severe forming operations.

**Full Anneal for Relief of Hardness Caused by Previous Heat Treatment.**—Heat to a uniform temperature within the range of 790 to 810°F. (421 to 432°C.). Soak for 2 hr., and cool slowly (approximately 50°F. decrease per hour) to 450°F. (232°C.), after which more rapid cooling is permissible. The slow cooling may be accomplished by allowing the material to cool in the furnace or bath, by removal to a heat-insulated chamber, or by placing between heated sheets of asbestos. Small parts may be buried in powdered heat-insulating material. If the work is allowed to cool in the salt bath, care should be taken to remove all traces of adhering salt. Quenching in water (from a temperature below 450°F.) may be used to avoid adhering salt, but there will be less danger of distortion if the work is allowed to cool in air.

The heat treatment of heat-treatable rivets must be closely controlled and held within the confinement of the following recommendations.

The requirements specified above for the heat treatment of general parts are applicable to the heat treatment of rivets except for the details of temperature, soaking times, equipment especially adapted to handling rivets, and elimination of direct contact between the rivets and the molten salt in salt baths. This latter requirement is taken care of in the design of the rivet heat-treating equipment described herein. This particular design is not mandatory but is presented as an example of equipment that has proved practicable, efficient, and suitable for the purpose.

**Prerequisite.**—All rivets should be anodized before reheat treatment; since rivets are purchased in the heat-treated condition, the first heat treatment performed by the fabricator is a reheat treatment, and prior anodizing is required. The function of the anodic film is to prevent intergranular oxidation.

Rivet heat-treating temperatures shall be shown as below:

Rivet alloy	Specification and grade	Temperatures of salt bath
17	43R5 Grade C	930–950°F. (498.5–509.5°C.)
24	43R5 Grade D	910–930°F. (487.5–498°C.)

**Rivet-soaking Period.**—The minimum soaking periods required for rivets is a variable depending on the type of alloy, the diameter of the rivet, and the type and efficiency of the equipment used. For the salt-

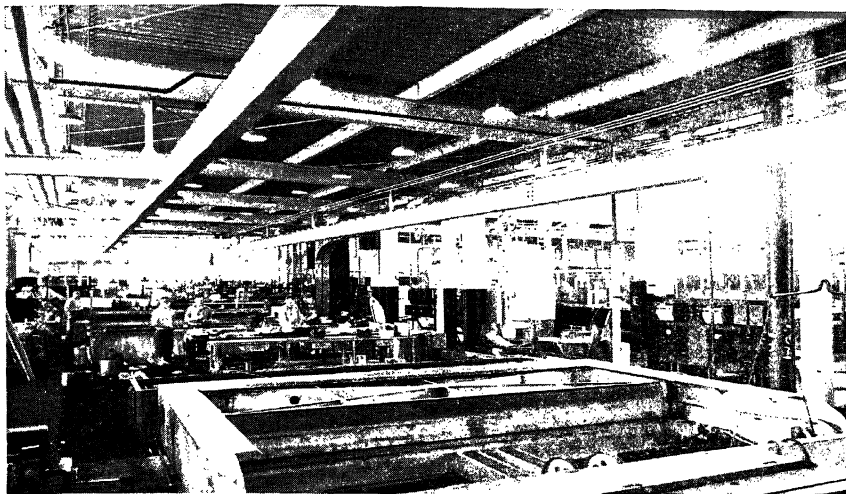


FIG. 36.—A general view of a process section showing arrangement of heat-treating salt bath for aluminum alloy and anodizing equipment.



FIG. 37.—A characteristic solid carbon dioxide refrigerator storage box for storing small heat-treated aluminum-alloy parts.

bath equipment described herein, in which the rivets are air-heated in metal containers, the minimum soaking period should be 40 min. For heat treatment in air furnaces provided with mechanical recirculation of air, the minimum soaking time should be 30 min. for alloy 17 and somewhat longer for alloy 24, depending on the characteristics of the furnace

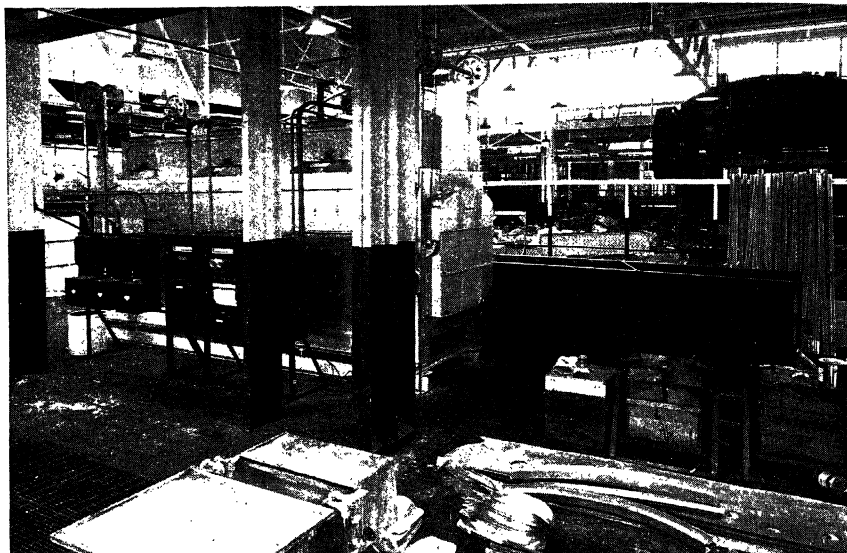


FIG. 38. View 1.—General view of air-type heat-treating furnace for aluminum alloy, showing control panel and quench tank.

and the manner in which the charge is arranged. In general, the optimum soaking period required to produce the desired results should be carefully determined by experiment to suit the individual equipment used.

**Heat-treating Rivets in Salt Bath.**—The design of the salt bath for heat treatment of rivets should be such as to eliminate direct contact of the rivets with molten salt. Equipment that satisfies this requirement is described hereafter. This equipment consists of a round tank or pot installed in a vertical electric furnace. The interior of the tank is fitted with a multiple number of liquid-tight vertical metal tubes, which receive the individual charges and from which the molten salt is excluded. These tubes are approximately 2 to  $2\frac{1}{2}$  in. in diameter, closed at the bottom, open at the top, and are spaced to provide not less than  $\frac{1}{4}$  in. clear separation in order to permit free circulation of the bath in contact with their outside surfaces. The top of the tank is fitted

with a cover plate through which the tubes project. A close-fitting insulated door is provided to cover the entire top of the tank and tubes. Thus, insofar as transfer of heat to the rivets is concerned, this type of salt-bath equipment constitutes an air furnace in which the heat is supplied by the molten salt.

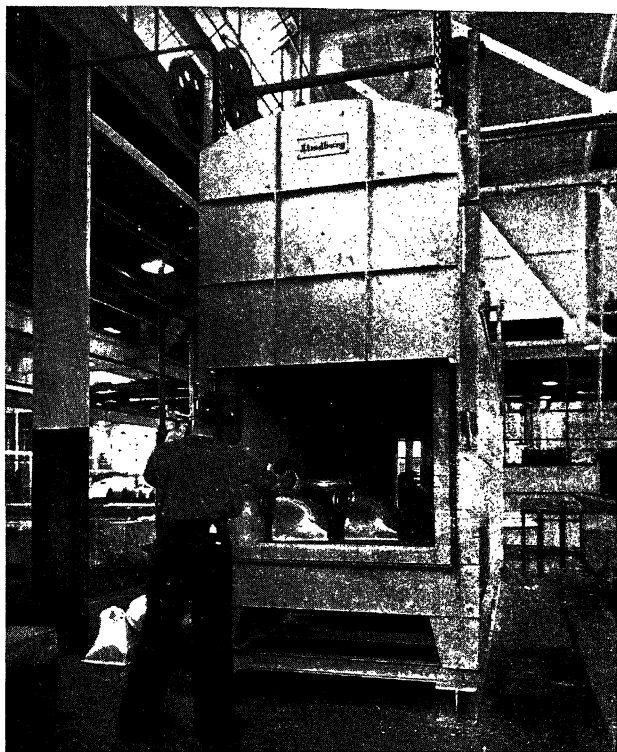


FIG. 39. View 2.—Air-type heat-treating furnace with doors open.

*Rivet Containers.*—In order to facilitate handling during charging and quenching, the rivet charges are contained in individual perforated metal tubes of suitable diameter to fit into the tubes, installed permanently in the bath, and provided with a suitable handle and cap. Neither the rivets nor the handling tubes (containers) contact the molten salt. The size of these containers and the quantity of rivets included in a charge are adjusted so that the uppermost rivets will be at least 4 in. below the surface of the bath. The length of tube that projects above

the surface of the bath should be sufficiently short to prevent appreciable cooling of the rivets as they are poured out of the tube into the quenching water. The following container tube sizes are recommended:

Rivet Length	Container Tube Size
Up to $\frac{1}{2}$ in.	1 in. O.D. $\times$ No. 17 (0.058) BWG
$\frac{5}{8}$ – $1\frac{3}{8}$ in.	2 in. O.D. $\times$ No. 17 (0.058) BWG
$1\frac{1}{2}$ in. and over	3 in. O.D. $\times$ No. 14 (0.083) BWG

*Quenching.*—After the rivets have soaked for the specified time, the container should be removed and the rivets poured immediately into

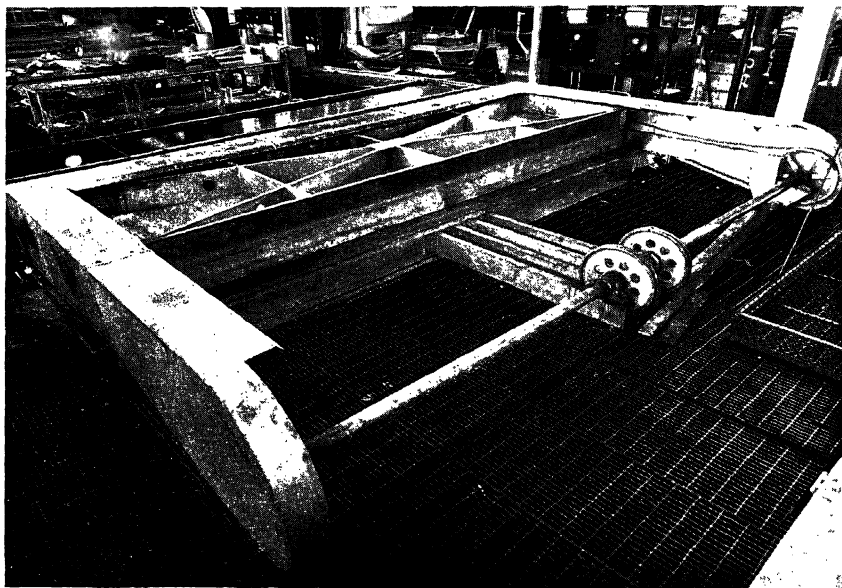


FIG. 40.—Salt-solution type heat-treating furnace for aluminum alloy.

circulating cold water, preferably ice water. The containers must not be quenched. Handling of rivets in the quenching water is facilitated by the use of perforated or wire receptacles immersed in the water for receiving the charge as poured from the container. The volume of the quenching water should be sufficient to avoid appreciable rise in temperature during quenching.

**Heat Treatment of Rivets in Air Furnaces.** *Furnaces.*—The furnace equipment for heat-treating rivets should be of the same class and subject to the same accuracy of control as that specified for general heat treating.

*Containers.*—To facilitate handling and to assure uniform temperatures in all parts of the charge during soaking, rivets must be placed in suitable mesh containers or perforated tubes arranged to permit free circulation of the furnace atmosphere throughout the load.

*Quenching.*—The quenching of rivets heat-treated in an air furnace must be accomplished in the same manner as with the salt-bath treatment. The container in which the rivets are heated should not be quenched. In all cases, the quenching operation must be performed with the utmost dispatch, as described in detail under the procedure for general heat treatment.

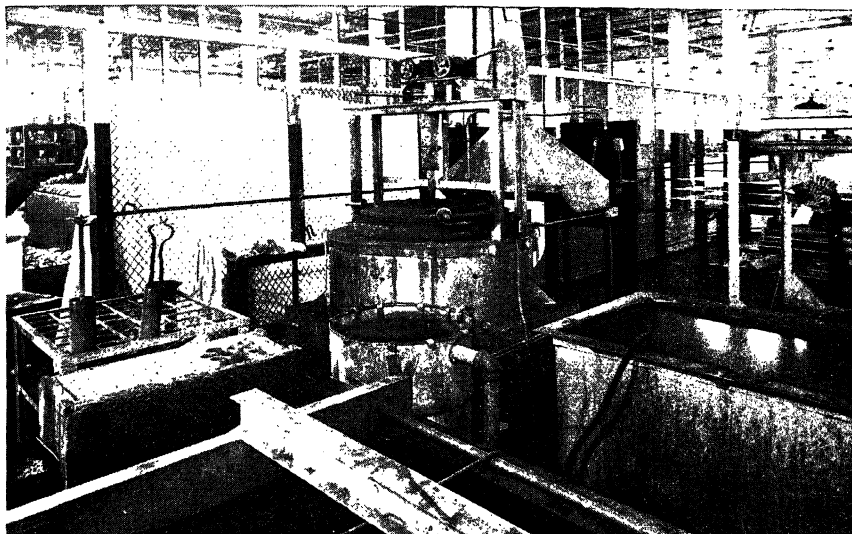


FIG. 41.—Aluminum-alloy rivet heat-treating furnace.

*Aging.*—Rivets of alloy 17 allowed to age at room temperature (less than 25°F.) are considered unfit for use 1 hr. after quenching and should be returned for reheat treatment. Rivets of alloy 24 should be returned for reheat treatment 20 min. after quenching. If, after quenching, rivets of either alloy are maintained continuously at a temperature not higher than 32°F., they may be used without reheat treatment for periods up to 48 hr. maximum, depending on the conditions of storage and depending on whether the material is properly workable when it is removed from refrigeration storage.

*Reheat Treatment of Rivets.*—Rivets are not to be reheat-treated more than 15 times.

*Rivet Inspection.*—Rivets should be subject to daily hardness inspection in the contractor's plant.

*Hardness.*—Daily hardness tests should be made on heat-treated rivets aged 24 hr. at room temperature after quenching. The minimum Rockwell hardness values are shown in Table 66.

TABLE 66.—MINIMUM ROCKWELL HARDNESS VALUES FOR HEAT-TREATED RIVETS OF ALLOY 17 AGED 24 HR. AT ROOM TEMPERATURE\*

Rivet Diameter, In.	Hardness (60 kg. $\frac{1}{16}$ -in. ball; read on red scale)
$\frac{3}{32}$	73
$\frac{1}{8}$	75
$\frac{9}{32}$	78
$\frac{3}{16}$	82
$\frac{1}{4}$	83

\* Hardness values for rivets of alloy 24 not available.

## CHAPTER XXI

### ANODIC TREATMENTS

Foreign investigations into the field of electrochemical protective coatings established the feasibility and need for a second line of defense against corrosion under subsequently applied organic protective coatings for aluminum alloys. Jenney, in "Anodic Oxidation of Aluminum and Its Alloys," divulged the methods employed in Germany in the use of anodic coatings. Beneough and Stuart, in British Patent 223994, Nov. 3, 1924, and, later, French and German patents, became instrumental in the establishment of anodic coatings brought about through the use of chromic acid as the electrolyte.

Federal specification AN-QQ-A-696 briefly covers the use of either chromic acid or sulphuric acid as the electrolyte limiting the use of chromic acid to aluminum alloys containing 5 per cent of copper or less. Sulphuric acid films are allowed for all parts except where the electrolyte may be trapped in parts or joints subject to stress.

It is highly important that the anodic film, regardless of the electrolyte employed, be continuous and free from breaks, scratches, or other damage. The allowance of contacted points due to the necessity of hanging, bundling, or otherwise suspending the parts in the electrolyte should be made with reservations. Anodized films should be freely rinsed, thoroughly dried, and painted as soon as possible to eliminate exposure to contaminating atmospheres or handling. Parts contaminated by finger marks, etc., may be superficially cleaned by the use of hydrocarbon or ester solvents.

A comparison of the use of chromic acid and sulphuric acid as comparative electrolytes is given in Table 67. The basis of the sulphuric acid electrolyte is given as the "alumilite process."

The anodizing of aluminum alloys in a chromic-acid electrolyte is given more attention in the chapter than the use of sulphuric acid, because chromic acid is the most universally used.

Characteristic analysis of flake chromic acid of 99 per cent purity may be illustrated as follows:

Chromic acid ( $\text{CrO}_3$ ).....	99.50% minimum
Sulphates ( $\text{SO}_4$ ).....	0.10% maximum
Chlorides (Cl).....	0.05% maximum
Insoluble matter.....	0.10% maximum



TABLE 67.—COMPARATIVE CHART SHOWING VARIATIONS IN PROCEDURE BETWEEN ALUMILITE AND CHROMIC-ACID ANODIZING PROCESSES

Electrolyte	Alumilite process (Sulphuric acid and water)	Chromic-acid process (Chromic acid and water)
Concentration	Depends on desired result: 1. Clear color and high durability 2. Colored for decorative value 2. Flexibility for cold-working	5-10 %
Voltage	12-24 volts, depending on concentration	40 volts
Time	Not specified	5-7 min. for 0-40 volts 30 min. at 40 volts
Current density	12-13 amperes per sq. ft.	1½-2 amperes per sq. ft.
Temperature	68-85° depending on results desired	95°F.
Temperature regulation	± 1°F.	± 4°F.
Tank material	Lead lined	Steel-plate fir batting for insulation
Tank width	Three times largest article treated or 12 in. clearance all around	Sufficient for work to clear
Rinse	One cold-water rinse One hot-water rinse (180-210°F.) Wooden tank with stainless-steel steam coil	One hot-water rinse (120-160°F.) steel tank gas-fired O.K.; chromic-acid stains are not undesirable
Thermo regulation and recorder	Required	Required
Recording voltmeter	Required	Required
Film thickness	0.0004 in. in ½ hr. 0.0008 in. in 1 hr. with 15 % H <sub>2</sub> SO <sub>4</sub> 12 amperes per sq. ft., 70°F.	Considerably thinner
Anode current efficiency	Apparent: 69 % Actual: 100 % plus	Apparent: Probably higher, since oxide is not so readily soluble in electrolyte
Racks	Aluminum 2S draws only 15.6 amperes per sq. ft. 17S draws 12.6 amperes per sq. ft. and is therefore better	Aluminum only
Intricate or porous castings	Treatment not allowed if electrolyte cannot be completely rinsed out	No separate operation required
Sealing	Separate operation (hot rinse with or without added chemicals)	No separate operation required
Throwing power	No comment	Exceedingly good
Color of coating	Light, transparent	Greenish gray
Absorption of stains	Highly absorptive in the unsealed condition (amorphous aluminum oxide); absorptive power disappears after sealing (aluminum oxide monohydrate Al <sub>2</sub> O <sub>3</sub> ·H <sub>2</sub> O)	Non-absorptive
Electrical conductivity	Fairly good in unsealed condition; good insulator after sealing	Non-conductive

This grade is most commonly used in anodic processes. Considerable attention should always be given the source of water supply in establishing the anodizing process. The softening of water with base exchange zeolites does not remove sulphates or chlorides, thus rendering an

operation involving the chemical softening of water useless. The best vehicle for use in forming the electrolyte is naturally soft water, if found available.

A brief examination of the equipment involved in the process of anodizing would reveal that four steel tanks of the proper size are necessary—one to hold an alkaline cleaning solution suitable for the process, one to hold rinse water following the cleaning process, one to hold to

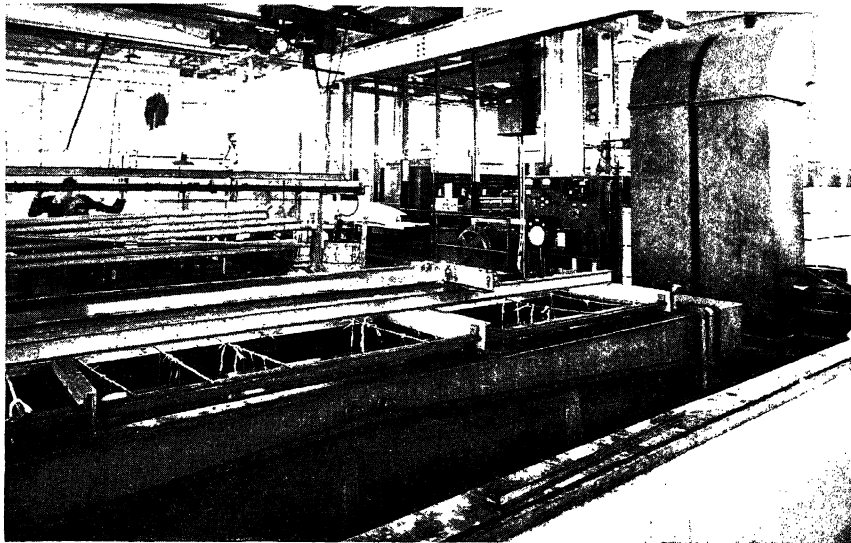


FIG. 42.—Anodizing tank and rack with view of controls.

the electrolyte, and one to hold the rinse water following the anodic treatment.

The cleaning tank should be provided with steam coils in order that the cleaning solution may be operated at temperature from 180 to 200°F. It should also be provided with a means of agitation. The anodizing tank or the tank holding the electrolyte should be provided with some means of heating and cooling in order that the electrolyte may be kept within the range of 90 to 95°F. The two rinsing tanks should also be provided with steam coils for heating to approximate temperatures of 150 to 180°F. A preferable arrangement is a hot-water rinse followed by a cold-water spray.

Electrical equipment recommended for the process should consist of a direct-current generator with proper controls allowing voltage regulation within a 20- to 40-volt range. Voltmeter of the recording ammeter

type should be installed with the proper starting compensators, switches, cutouts, etc., necessary to proper control and operation of the generator.

Racks or other means of holding the part in the electrolyte should be made of aluminum compensated to induce proper current carriage.

Current induction should be controlled by the use of a rheostat whereby the voltage may be raised slowly from 0 to 40 volts at approximately 5 volts per minute. Current density of the chromic-acid electrolyte may be generally included between  $\frac{1}{2}$  to 2 volts minimum.

Some general instructions for the detail anodic treatment of parts have been recommended to the industry by the Turco Products, Inc. which are very easily followed. These are as follows:

**Anodizing of Hollow Objects.**—Small, hollow objects should be placed in the solution with the body opening directed upward to avoid air or gas pockets. Air or gas bubbles that cannot escape from the vessel will prevent the anodic film from forming where the chromic acid does not have access to the metal. Air pockets also act as insulators, producing a local hot spot that may lead to burning of the aluminum.

Larger hollow objects, such as tanks and the like, should have an auxiliary cathode placed inside. This may be in an aluminum rod or an aluminum wire on which glass beads or porcelain disks have been threaded to prevent contact and short-circuiting between anode and cathode. Provision also must be made for cooling the chromic acid inside the tank. One of the easiest ways to accomplish this is to pump the chromic acid into the tank so that it continuously overflows. The pump discharge should be at the bottom of the tank being anodized so that the entire body of anodizing solution within the tank is kept in motion.

Much the same technique may be used in the anodizing of tubing. Tubing should be placed in the tank in an inclined position so that any local heat tends to induce circulation by a thermosiphon effect. The chromic acid may be pumped through the tube if necessary.

Objects with flanged edges that tend to trap air or gas under the flanges are best handled by attaching the clamp that holds the flanged piece to a motor-driven arm like those commonly used in nickel plating to shake off gas bubbles.

It may be observed here that defective castings that contain pores or blowholes are likely to be rejected after anodizing. Gas collects in the pores, preventing contact of the electrolyte. Thus the film does not form in the pores. Anodizing is not a practical method of sealing porous castings. Such castings should be treated by the silicate of soda process, —i.e., dip in hot silicate of soda and follow by a weak acid dip to insolubilize the silicate.

**Anodizing of Rivets and Screws.**—Cylindrical or cone-shaped containers are usually provided for anodizing of very small parts. An

aluminum anode rod is usually permanently fixed in the center of the container. When the container has been filled, a cover is fitted into it so that it presses down tightly against the small articles.

**Anodizing Clamps.**—It is essential that the contact clamps should hold the work with sufficient tension that it cannot work loose during anodizing. This is one of the considerations that led to the development of the coil-spring clamp. If there is any play between the contact clamp and the object being treated, not only is there loose contact that may lead to overheating but the momentarily exposed contact surface will itself be anodized and the contact area correspondingly reduced. With heavy objects, it is customary to use bolts or screws to ensure a solid point of contact. These should be pure aluminum.

**Stripping Anodic Coating from Clamps and Carriers.**—At the same time that the work is being anodized, the clamps and carriers also acquire the anodic coating. It was formerly necessary to remove this coating by filing the points of contact before the clamps could again be used. This is a time-consuming operation.

Filing can be eliminated by immersing the clamps for a few seconds in a 50 per cent solution of nitric acid to which  $\frac{1}{4}$  oz. per gallon of a material comparable to Turco Nitro-Brite has been added. The nitric-acid solution should be used in a paraffin-lined, shallow wooden tray of just sufficient depth to cover the clamps. The total capacity of the tray need not be more in most cases than 1 or 2 gal. It is preferable to work with small amounts of solution since this makes it economical to discard the solution and prepare a new one as soon as the copper concentration reaches the point where a gray deposit shows on the clamps during immersion. The gray deposit is a strike coating of copper.

These precautions should be observed:

1. Do not immerse iron or steel parts into the nitric-acid Turco Nitro-Brite dip solution. Even the cadmium-plated bolts on the clamps should be kept out.

2. Use a separate bath for high copper alloys, such as brass.

**Color of the Anodic Deposit.**—Typical color of the anodized film is an iridescent gray. The exact shade no doubt depends upon the thickness of the film and upon the amount of chromic oxide absorbed in it. Anodic operators claim to be able to judge the quality of the anodizing by the color of the film and likewise to be able to judge the age of the bath by the intensity of color. The latter, in any event, is quite probably correct, since the older baths are likely to have a lower content of free chromic acid and to give thinner films.

The composition of the alloy itself influences the color of the anodic film considerably. Alloys high in silicon give very dark anodic coatings. Sometimes silicon is so much in evidence that a sooty coating can be

wiped away from the sheet with a soft cloth. Again, it seems to be an observed fact that anodic baths that have been used for a considerable time in anodizing high-silicon alloys will give darker coatings on the wrought alloys.

It seems to be a safe conclusion that there is no necessary correlation between the color of the anodic film and its resistance to corrosion.

General instructions also are given by this company for the maintenance and control of the anodizing solution that are quite characteristic of general practice. Water should be added as necessary to compensate for evaporation losses. Additional chromic acid will also be necessary to take care of losses from drag-out, losses due to the formation of aluminum compounds in the solution, and possible losses by valence changes.

Generally speaking, the American practice is to maintain a free chromic-acid content of not less than 5 per cent. It should be noted that in this 5 per cent, chromium combined as salts of aluminum and iron and trivalent chromium are not to be included.

Routine analyses of the bath should be made by the laboratory at regular intervals and should cover

1. Free chromic acid.
2. Chlorides.
3. Sulphates.
4. Total bases: aluminum, trivalent chromium, iron.
5. Hexavalent chromium.

These should be recorded and filed with the records mentioned under Instrumentation and held ready for forwarding to Washington if requested.

Many analyses are time-consuming and can hardly be made a matter of daily control. For daily use, simpler short-cut tests should be used.

In a practical way, the condition of the bath may be estimated by current density determinations. Since good deposits can be obtained with current densities as low as 0.9 amperes per square foot, the range 3.5 to 0.9 amperes per square foot may be used as a measuring stick of bath concentration, additional chromic acid being added whenever the current density falls below 1.0 until such time as further additions are ineffective. The preceding figures are for 24ST. Current density varies with alloy composition.

Other short-cut methods are, however, considerably more rapid and possibly more conclusive.

One of the most promising control methods is that suggested by Manuel Sanz. He proposes to use the glass electrode titration figure from the initial pH to the point at which aluminum just begins to precipi-

tate as a measure of the free chromic acid content. For laboratories that have Beckman pH meters with electrometric titration assemblies, this would seem to be a very suitable procedure and one that would save much time. By continuing the titration further and by drawing curves, Mr. Sanz is able also to estimate the aluminum content of the solution by interpolation from his curves. The Sanz method has not yet been published, but it is hoped that it may shortly be available in the journals.

The U.S. Bureau of Standards, in *Research Paper* RP961, proposes the control of the anodizing solution strictly by means of pH and presents a curve showing the relation of pH to free chromic acid content. The pH of a 5 per cent chromic acid solution is approximately 0.4; at pH 2.00, the free chromic acid content is zero. The authors of the research paper have not made public the experimental results upon which their conclusions are based, and their recommendations have been received with considerable reserve. The simplicity of the method certainly suggests that it should be given careful study under plant-operating conditions.

In another method, it is proposed to measure the free chromic acid content with a simplified conductivity bridge. The Solu-Bridge is an inexpensive instrument suitable for such control work. This instrument is made by Industrial Instruments, Inc., and may be obtained from Turco Products, Inc.

It is considered good practice when the anodic bath shows signs of exhaustion to drain the tank and prepare a completely new solution.

**Composition of the Anodizing Solution in Use.**—From a summary of the analyses of electrolytes of known efficacy, it would appear that for good results the solution should conform to the following minimum conditions:

1. The free chromic-acid content shall not be less than 2.5 g. per 100 cc.
2. The reduced chromium shall not be more than the equivalent of 0.5 per cent  $\text{CrO}_3$ .
3. The combined percentage of  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  shall not be more than 0.3 g. per 100 cc.
4. The chloride content shall not be more than the equivalent of 0.05 g. Cl per 100 cc.

The first noticeable effect of continued exposure to chromic-acid fumes is bleeding from the nose. As pointed out, perforation of the nasal septum may ultimately result.

Scratches, cuts, abrasions, or rashes are inflamed by chromic acid and, if neglected, may lead to chrome ulcers. Rubber gloves, aprons, and rubber boots should be worn by the workmen. It is a wise precaution to inspect the racks for sharp edges that may cause flesh wounds.

Periodic examination of the workmen in the anodic department by a competent physician is a worth-while precaution. If the examination should show an increase in the number of cases of nasal irritation, the operation of the ventilating equipment should be given careful study. An increase in the number of cases of skin trouble may show a tendency toward carelessness among the workmen or substandard working conditions. Some workmen appear to have, or to develop, a definite allergy to chromic acid. Since no cure is possible in such cases, they should be kept out of the anodic department.

For the purpose of analytical control of the process, the following methods may be used:

1. *Chromic Acid*.—Twenty-five cc. of the bath solution is taken and diluted to 500 cc. in a calibrated flask. Fifty cc. of this diluted solution (equivalent to 2.5 cc. of the original) is then taken and an excess of 0.1*N* ferrous ammonium sulphate run in from a burette, the excess being titrated with 0.1*N*  $\text{KMnO}_4$  (approximately 10 cc. 1:1  $\text{H}_2\text{SO}_4$  added).

1 cc. of 0.1*N* solution = 0.00333 g.

$\text{CrO}_3$  or 0.1333 g. per 100 cc. of bath solution

2. *Total Chromium*.—Fifty cc. of the diluted solution is taken as before, a little  $\text{H}_2\text{SO}_4$  added, diluted to about 200 cc., and boiled with an excess of  $\text{K}_4\text{MnO}_4$  for 20 min., after which the excess permanganate is destroyed with a little manganese sulphate.

The solution is cooled, filtered through asbestos and the filter washed with hot water. The cooled filtrate is then titrated as in the previous determination, the result giving the quantity of  $\text{CrO}_3$  originally present in the solution.

By difference, the quantity of  $\text{CrO}_3$  that has been reduced can be obtained.

3. *Total Bases* (Cr, Al, and Fe).—Take 25 cc. of the bath solution, add a few grams of  $\text{NH}_4\text{NO}_3$ , dilute, and heat to boiling. Add a slight excess of  $\text{NH}_4\text{OH}$ , boil again, and filter off mixed hydroxides, wash, ignite, and weigh residue of  $\text{Cr}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ . By calculating the weight of  $\text{Cr}_2\text{O}_3$  present, from the percentage of reduced chromic acid (1 g.  $\text{CrO}_3$  reduced gives 0.760 g.  $\text{Cr}_2\text{O}_3$ ), and subtracting from the total weight of oxides, the weight of  $\text{Al}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  is obtained.

If Fe is present in any appreciable quantity and the separate percentages of Fe and Al are required, the iron may be precipitated alone from the original solution by the addition of an excess of  $\text{Na}_2\text{O}$ . Filter and redissolve the Fe (H) with dilute  $\text{H}_2\text{SO}_4$ , make neutral with  $\text{NH}_4\text{OH}$ , and reduce the Fe with  $\text{H}_2\text{SO}_3$ . Acidify again with  $\text{H}_2\text{SO}_4$ , boil off  $\text{SO}_2$ , cool, and titrate Fe with 0.1*N*  $\text{KMnO}_4$ .

1 cc. 0.1*N*  $\text{KMnO}_4$  = 0.00798 g.  $\text{Fe}_2\text{O}_3$

If the total weight of oxides and also the weight of  $\text{Cr}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$  are known, the weight of  $\text{Al}_2\text{O}_3$  is then obtainable by difference.

4. *Chlorides*.—Weigh out 10 g. of pure granulated zinc in a 400-cc. tall beaker, and wash with dilute  $\text{HNO}_3$  and water to remove any corrosion deposit on the zinc. Run in 100 cc. of the bath solution, and add 40 cc. of pure concentrated  $\text{HNG}_3$ . When the reaction has ceased and the chromic acid is reduced to chromium nitrate, filter the solution through paper pulp, add silver nitrate, and boil to coagulate the silver chloride. Filter off the latter in a Gooch crucible, washing with hot water and finally with alcohol. Dry in an air oven at  $105^\circ\text{C}$ ., and weigh. Calculate the chloride content as grams  $\text{NaCl}$  per 100 cc.

$$1 \text{ g. AgCl} = 0.4079 \text{ g. NaCl}$$

5. *Sulphates*.—Take 8 to 9 g. zinc, wash, and add 100 cc. of bath solution, as in chloride determination. Add 35 cc. of pure concentrated  $\text{HCl}$ . When the reaction has ceased, filter through pulp, and add barium chloride solution. Boil, and allow to stand overnight. Filter off  $\text{BaSO}_4$ , wash, ignite, and weigh. Calculate sulphate as grams  $\text{H}_2\text{SO}_4$  per 100 cc.

$$1 \text{ g. BaSO}_4 = 0.4202 \text{ g. H}_2\text{SO}_4$$



## CHAPTER XXII

### CADMIUM-PLATING STEEL PARTS

Cadmium-plating detail requirements for Army and Navy parts are given in Federal specification AN-QQ-P-421. The deposition of cadmium by electroplating is the most universally used plating-type coating in the aircraft industry. Its resistance to corrosion is very high, and it is used for the protection of steel parts. The mechanics of application involve a cleaning method, the plating operation, and a bright dip. Blum and Hogaboom, in "Principles of Electroplating and Electroforming," devote a great deal of space to the requirement and necessity of cleaning and the various methods. According to their recommendation, two kinds of foreign materials most likely to be found on metallic surfaces are oxides that are made up of rust and scale and other foreign matter; grease, oil, and other organic contamination. The oxides are readily removed by abrasion such as shot- or sandblasting, wire brushing, etc., or by pickling in the proper acid solutions. The removal of grease and other similar substances may be accomplished as well by the methods mentioned but removal is more economical by electrocleaning or by the use of organic solvents.

The Army and Navy requirements, as outlined under the specifications discussed, are somewhat brief but important. For instance, the requirement for the sequence of plating is specified at the time when all brazing, welding, etc., have been completed. In the case of threaded parts, the plating is applied to the threads without the necessity of undercutting the threads except in specific instances where drawing tolerances allow for it.

Cadmium is deposited directly onto the metal without any preliminary coating, such as copper or nickel, usually employed in other electroplated coatings. The requirements for the resultant plated coating restrict the application so that it involves as little pitting and abrasion prior to plating as is necessary.

The plating thickness by deposition according to acceptance standards should be not less than 0.0005 except in such cases as integral parts that are threaded externally. For externally threaded parts, the thickness is restricted to not less than 0.0002. In determining the thickness of the plating, the amount that is deposited on an actual smooth surface is always considered and is not to be confused with the amount deposited

in pits and craters in the surface of the metal. The general accepted test for the determination of thickness is by the "drop-test method," described as follows.

**Apparatus.**—Apparatus shall consist of a 250-ml. separatory funnel connected by rubber tubing to a straight two-way glass stopcock, the lower end of which is drawn to a small orifice.

**Test Solution.**—The test solution shall be as follows:

Ammonium nitrate (C.P.).....	110 g.
Hydrochloric acid (specific gravity 1.18).....	10 ml.
Distilled water to make.....	1 l.

**Procedure.**—The funnel shall be filled with the test solution and the upper cock opened wide. The rate of flow from the orifice shall be adjusted by means of the lower cock to not less than 80 nor more than 120 drops per minute. The flow of solution is thereafter controlled by means of the upper cock. Immediately before testing, the plated article shall be cleaned with an organic solvent, followed by light rubbing with pure magnesium-oxide paste, rinsing in water, and drying. The surface to be tested shall be considered to be sufficiently clean when the water rinse shows freedom from "water break"—*i.e.*, when water wets the entire surface. The cleaned article shall be supported by a rack, clasp, or other suitable means so that the test surface is at an angle of 45 to 60 deg. from the horizontal and about 2 in. below the orifice. During test, the temperature of the solution and the plated article shall be not less than 16°C. (60°F.) or more than 27°C. (80°F.). The upper cock is then opened wide, and the elapsed time in seconds from the instant that the first drop strikes the surface until the base metal is first revealed is determined, preferably with a stop watch. Each second is equivalent to a thickness of 0.00001 in. of cadmium. The spent solution may be caught in a glass or porcelain dish and shall not be used for subsequent tests.

The cadmium plating of springs or similar parts subject to bending that contain more than 0.40 carbon and whose diameter or thickness ready for use is less than  $\frac{1}{4}$  in. must be baked for 3 hr. at 375°F. after plating to offset embrittlement due to the plating operation.

The equipment involved in the setup of a cadmium-plating unit depends a great deal on the type of plating to be done. The "still-plate" method is devoted to the plating of large parts, whereas the barrel-plating method is designed for the plating of bolts and nuts, etc. If "still plating" is to be done, the equipment should include necessary generator and motor set, bus bars, rheostat, etc.; a steel tank properly protected where the chemical cleaner may be installed; a tank for the rinsing, which should be equipped with a heat unit capable of operating

the rinse water at a temperature of not less than 180°F. (a cold-water spray is beneficial following the hot-water rinse); a wood lining or some similar material impervious to acids, to be installed for the use of the pickling solutions; a tank properly equipped with the bus bars, cadmium baskets, etc., to be used for plating; another tank for rinsing after plating, which may be operated efficiently at 180°F.; and, finally, a tank for the bright-dipping of the parts after plating.

If barrel plating is to be done, the proper setup of the plating barrel and tank should be installed instead of the regular tank as mentioned before.

The proper line-up or installation is greatly dependent on the size of space available and the quantity of plating to be done. In the electrical installation, every effort should be made to locate the generator close to the plating tanks to eliminate line-voltage drop.

Considerable space has been given to proper methods for the cleaning of aircraft parts prior to plating and finishing in Chap. XIV. Therefore, it is not necessary to repeat the formulas and recommendations for pre-cleaning and pickling.

The most commonly used solution combination for both still and barrel plating is shown in the table that follows.

It is highly important that the ratio of total sodium cyanide to cadmium fall within the limits of 3.6 to 3.9 in order to maintain proper cathode efficiency, as well as to minimize the possibility of the formation of sodium carbonate by the decomposition of the cyanide. The solution should be checked frequently and cyanide added in order to maintain the limits.

TABLE 68.—RECOMMENDED FORMULAS AND CONDITIONS FOR CADMIUM PLATING

	Still tank	Barrel
Cadmium oxide.....	3.4- 5.1 oz. per gal.	2.6- 4.3 oz. per gal.
Sodium cyanide.....	11.5-17.5 oz. per gal.	9.0-14.5 oz. per gal.
Ratio of total sodium cyanide to cadmium as metal.....	3.8	3.8
Current density.....	15-45 amperes per sq. ft.	5-25 amperes per sq. ft.
Voltage.....	1-4	7-14
Temperature.....	80-95°F.	80-95°F.

According to the best recommendations by a number of operators, 1.5 to 3.2 oz. per gallon of caustic soda is necessary to promote the highest conductivity efficiency. The caustic is not added as such but appears through the reaction of the cyanide and cadmium oxide. If, on analysis, the solution shows less caustic than that recommended, the difference should be effected by the addition of some caustic in its original form.

Sodium cyanide as such should be maintained approximately between 1 to 4 oz. per gallon.

In the practical application of cadmium plating and recommendations as to the aircraft parts requiring such protection, it can safely be said that all steel (not stainless) parts require cadmium plating. Further, such cadmium-plated parts, in order to be acceptable to the government procurement agencies, must withstand 250 hr. salt-water-spray corrosion test, conforming to specification AN-QQ-S-91.

In instances where cadmium-plated parts are to receive subsequent organic top coating, it is best to dip them into a 5 to 6 per cent chromic-acid solution for a short period of time in order to passivate the surface.

Because cadmium plating requires considerable production in order to make an installation pay for itself, manufacturers contemplating doing their own cadmium plating would do well to obtain outside prices before making such an installation. Further information on cadmium plating is so greatly dependent on specification and structural requirements that it is thought best to leave the balance of such information available through specification to the proper authorities.

## CHAPTER XXIII

### MAGNETIC INSPECTION

The service demands of aircraft steel parts require minute inspection and examination not only for flaws apparent to the naked eye but for strains and cracks developed within its structure. Minute cracks or other flaws in structure members of aircraft parts present a future hazard to the primer structure of the entire airplane. For instance, some essential parts that can be considered in this category are engine mounts, frames for main stress bearings, landing-gear struts, propeller blades, wing-hinge fittings, etc.

Many times, flaws in the microstructure of the part will develop through fatigue and stress into dangerous failures.

The Magnaflux Corp. of Chicago, through the research of such men as Doane, de Forest, Betz, McCune, and other members of the staff, have made possibly one of the greatest single contributions to aircraft safety in the development of the Magnaflux machine by the study of magnetic principles as applied to magnetic substances.

Magnetic principles surrounding the magnetic inspection of steel parts for aircraft have been explained very thoroughly by Doane and clarified in their application to aircraft structures by R. R. Moore, senior metallurgist, U. S. Navy, Naval Aircraft Factory.

Moore has explained that generally substances can be divided into two separate classes according to their reaction when placed in the magnetic field. One class he determines as paramagnetic and defines as that class whose magnetization direction follows that of the magnetizing force and whose intensity of magnetization parallels are increased with that of the magnetizing force. The other class that he determines as diamagnetic is characterized by the magnetization being directly opposite to the magnetizing form; the magnetization increases in the opposite direction to that of the magnetizing force, which, simply explained, means that the diamagnetic materials are repelled rather than attracted by a magnet.

For a brief description of the process method in applying magnetic inspection, it will be found that there must be provided a method for the application of both circular and bipolar methods. The circular method should be arranged in such a way as to induce a magnetic flux in the piece being tested by means of high amperage, low voltage, with direct current passed through to the piece.

The bipolar or longitudinal method should be capable of inducing magnetic flux in the piece being tested when it is placed in the magnetic field between the poles of the electromagnet or by means of a solenoid or coil carrying a direct current. The cleaning method has been discussed in the preceding paragraph.

A demagnetizing unit should be a part of the operation and should conform to either the open-coil or box type, capable of the proper capacity for satisfactory demagnetizing the types of pieces inspected.

The magnetic substance employed for the determination must be applied by either the wet or the dry method. If the wet method is employed, best results are obtained by the use of the black color. The usual solution used in the wet process consists of a suspension of the



FIG. 43.—Circular type of magnetization.

magnetic paste or powder in a liquid comparable to specification P-S-661 or a light oil such as kerosene or its equivalent. However, if impression pictures are to be made, according to the latest method recommended by the Naval Aircraft Factory, carbon tetrachloride may be used as the vehicle. The concentration of the solution should be not less than 1 oz. by weight of dry or paste to 1 gal. of vehicle.

The magnetic inspection on all parts should be performed in a manner to provide satisfactory detection of defects or having axis in any direction relative to the axis of the piece being inspected. A complete inspection test should always consist of one or more separate magnetic-inspection operations that include the lines of force transverse to the defects in the piece.

If the circular method is employed, it should be understood that the lines of magnetic force in any one plane take the form of concentric rings around the axis of the current. Therefore this method should be applied for the determination of defects with axis closely parallel to the axis of the current. Usually this method is applied for the detection of defects with the axis of the current through the piece.

If the bipolar method is used, it should be understood that the lines of magnetic force are approximately parallel to the axis of the piece. Therefore, this method should be applied for the determination of defects whose axes are closely transverse to the axis of the piece.

There are two methods for the application of the magnetic substance:

1. Actual or continuous methods, which involve the application of the magnetic substance to the piece while the magnetizing current is flowing.

2. The residual method, which involves the application of the magnetic substance to the piece after it has been magnetized and the magnetizing current has been shut off.

For most general use, the actual or continuous method is recommended.

After the magnetic-inspection operation has been made, all parts should be satisfactorily demagnetized. It is highly necessary that such parts be demagnetized following each magnetizing operation in order to obtain proper indications.

Supplementary to the information given above, the general requirements for military and naval aircraft activities are outlined below:

1. Each part should be examined after bipolar magnetization and also after circular magnetization. After testing under one condition of flux, the part should be demagnetized before magnetizing to the other condition.

2. The wet method of indicating should be used.

3. Before applying the indicating solution to parts containing oil holes or other openings that lead to cavities that are difficult to clean, the holes should be plugged with grease to prevent entrance of the Magnaflux solution.

4. In producing circular magnetization by passing the current directly through the part, the contacting ends of the part should be protected against local burning by inserting sheet lead or copper-braided tape between the ends of the part and the contact plates.

5. After the magnaflux test has been completed, all parts should be completely demagnetized.

6. After demagnetizing, each part should be checked for magnetism.

7. After completing the test, all parts should be thoroughly cleaned with the cleaning solution. All plugs in holes and cavities should be removed.

8. The magnetizing unit and indicating solution should be checked periodically to ensure that both are up to strength.

The specific procedure outlined below should be observed by naval aircraft activities. (USAAF accepts in general the activities outlined.)

1. Magnetize the part using the maximum rated current strength that can be developed on the machine, and apply the indicating solution while the magnetizing current is flowing (the continuous method). If no indications of defects appear or are observable, the part is acceptable.

2. If indications of defects appear, wipe the surface clean of all indications, and apply the indicating solution again without the current flowing (the residual method).

3. If the indications do not reappear when tested with residual magnetism, it signifies, in most cases, that the defects are not serious and the part may be accepted. However, certain vital and highly stressed parts are exceptions to this procedure.

4. If the indications reappear when tested with the residual magnetism, demagnetize, and magnetize again at the current strength indicated in Table 69. If the indications do not appear at the specified current strength, the defects are of a minor nature, and the part is acceptable. If the indications appear at the specified current strength, the part should be rejected.

a. In testing with bipolar flux produced by the direct-current solenoid or by wrapping irregularly shaped parts with a conducting cable, the magnetizing current strength should be about 2,000 amperes.

b. In testing with circular flux, the magnetizing current strengths indicated in Table 69 should be used.

5. The foregoing procedure should be carried out independently under bipolar and circular magnetization. After testing under one condition of flux, the part should be demagnetized before magnetizing to the other condition.

### **Procedure for Demagnetization.**

1. The demagnetizing unit with the smallest opening that will receive the part should be used.

2. Starting from a position about 1 ft. in front of the hole, move the part slowly toward and into the opening. Then slowly withdraw it until about 1 ft. from the end of the unit. Repeat this process several times. Make all movements toward and away from the demagnetizer slowly and steadily.

3. Small parts should be held near the sides of the hole upon entering the solenoid.

4. In the case of parts that do not readily lose their magnetism, it is sometimes helpful to tumble and rotate the parts in various directions while passing in and out of the demagnetizer.

5. Immediately after demagnetization, parts should be tested for magnetic condition with the aid of a compass. The part should not cause deflection greater than 3 deg. when it is passed 6 in. in front of the face of the compass.

6. The portable alternating-current equipment should be used for parts difficult to magnetize.



a. The same procedure as outlined for the direct-current equipment should be used except that the continuous method must be used.

b. The same apparatus can be used as a demagnetizer by reducing the applied alternating current in small steps.

### **Effect of Protective Coatings and Electroplating.**

1. Anticorrosion protecting coatings such as primers, paints, cadmium plating, chromium plating, zinc plating, and aluminum-sprayed coating show up indications.

2. Nickel-plated parts indicate only the large cracks open to the surface of the base metal or cracks through the nickel plating.

### **Interpretation of Magnaflux Indications (Wet Method).**

1. *Cracks.*—When the crack is open to the surface, the powder forms a well-defined, thin, sharp pattern built up to a readily discernible height. If the crack is not open to the surface, the powder forms a somewhat broader line and may be a little fuzzy.

2. *Cavities below the Surface.*—If not much below the surface, the powder will have a tendency to smear over the whole projected area of the cavity rather than follow its outline.

3. *Scratches.*—Scratches and tool marks do not appear so dense as cracks.

4. *Inclusions.*—When in the form of seams or hairlines, inclusions appear as cracks, but the powder does not tend to pile up so high. Seams and hairlines do not show up so quickly as cracks when the part is first magnetized.

5. *Internal Strains.*—Internal strains give very faint indications and sometimes disappear after a time.

6. *False Indications.*—False powder patterns are caused by polar effects due to keyways, drilled holes, sectional changes, splines, joints, changes in magnetic properties, weld edges, etc., or by sluggish indicating solution.

7. *Defects* of the same character and equal depth will be more sharply defined on a thin piece than on a thick piece.

### **Common Types of Defects.**

1. *Bar Stock.*—Seams, surface laps, cracks, hairlines, and elongated inclusions. Most bar-stock defects lie parallel to the axis of the bar.

2. *Foggings.*—Laps, forging cracks, bursts, seams, hairlines, elongated inclusions, and heat-treating cracks. These defects exist in all directions.

3. *Newly Manufactured Parts.*—All defects listed in (1) and (2).

4. *Service Parts.*—Defects listed in (1) and (2), in addition to cracks due to overload, shock, sharp corners, shoulders, splines, threads, and cracks that have developed from fine inclusions and seams.

**Defect Requirements.**—The following general rules must be adhered to in deciding the acceptability of parts that show magnaflux indications:

1. Parts that contain cracks or laps that are known to be open to the surface are not suitable for service.

2. Parts that contain defects that extend over or within  $\frac{3}{16}$  in. of a shoulder, edge, corner, fillet, or hole are not suitable for service.

3. Parts that contain defects, the indications of which show on both sides of a section, are not acceptable for service.

4. Seams, hairlines (very fine seams or checks), and long inclusions are not permissible on highly stressed parts such as gears, valve springs, piston pins, valves, propeller blades.

The paramagnetic substances classified by Moore are iron, steel, nickel, cobalt, and the various alloys of these metals. According to Moore's work, the following materials whose permeability varies with intensity of the magnetic field are

Iron.....	200
Nickel.....	23
Copper.....	14
Platinum.....	0.000029
Aluminum.....	0.0000018

The diamagnetic materials are

Copper.....	0.00000082
Lead.....	0.00000124
Silver.....	0.00000151
Antimony.....	0.00000520
Bismuth.....	0.00001380

Permeability is defined as the ability of the material to develop magnetic flux. There are two definitions employed in the following paragraphs that are important to retain.

1. Residual magnetism.

2. Demagnetization.

Demagnetization is the operation setting up a magnetizing force in the direction opposite to the force that develops the magnetization. Residual magnetism is the magnetization of a non-magnetic material by an increased magnetic field.

Briefly, the magnetic principle is predicated on metallic discontinuities or abrupt changes in permeability detected by the distribution of finely divided ferromagnetic particles, either dry or contained in a vehicle over the surface, the part, of course, being magnetized before application.

The figures accompanying this chapter show two views of an actual Magnaflux installation. This machine is one of the latest types and is built to handle a wide variety of parts.

The practical application of magnetic inspection includes a definite routine and method. General notes requiring the routine and method involve one important point—cleaning. All parts after Magnaflux inspection should be washed free from oil and foreign matter with an acceptable solvent.

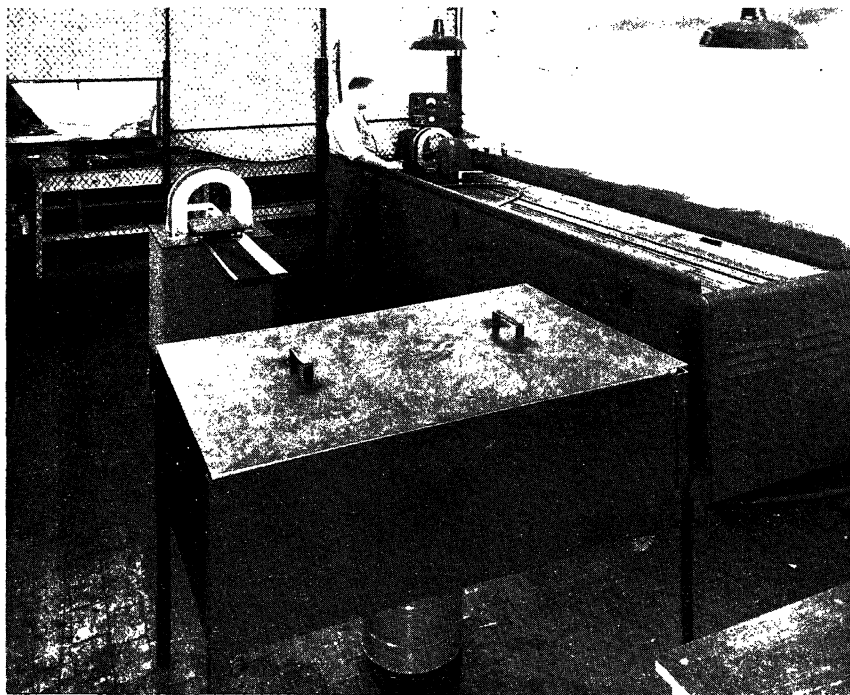


FIG. 44.—Magnaflux installation showing unit, demagnetizer, and rinse tank.

All parts requiring magnetic inspection should be identified in some fashion, after the inspection has been made, with a stamp or some similar mark to identify the part as having received the inspection.

In general, parts requiring magnetic inspection should conform to the following: Forgings should be magnafluxed at the time of receiving; finish-machine forgings should always be given a final inspection after die marking, welding, and heat treatment but if possible should be inspected prior to cadmium plating; welded assemblies must be inspected after all welding normalizing and/or heat treatment and finish marking. Bolts, pins, and nuts may be magnafluxed after plating. Springs,

however, should be magnafluxed after the final inspection operation, depending on which of the following operations is considered the final one: forming, heat treating, strain relief, cadmium plating, or relief or embrittlement.

If parts to be inspected are found too dark to show the flux particles, they may be sprayed or dipped in a coat of white lacquer, dried for 15 min., and then inspected. The white lacquer should, however, be removed after inspection.

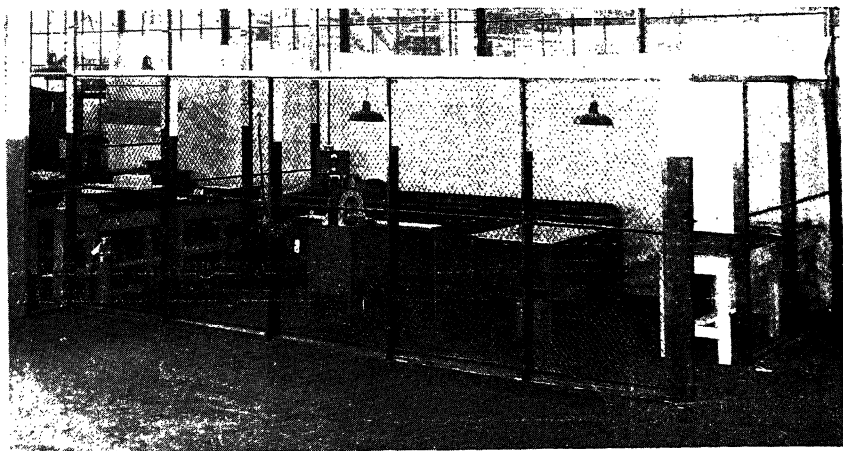


FIG. 45.—Proper enclosure method for certified magnetic inspection equipment.

For the application of a general rule for parts requiring magnetic inspection, the following will hold true:

#### **Engine Sections.**

1. Engine-mount forgings.
2. Engine-mount rings.
3. Engine-mount cluster fittings.

#### **Landing Gear.**

1. Forgings.
2. Welded assemblies.
3. Axle.

#### **Bolts, Pins, and Nuts.**

All bolts, pins, and nuts having a required tensile above 150,000 psi. should be magnetic-inspected.

**Hydraulic System.**

1. Welded assemblies.
2. Welded fittings.
3. Pistons and cylinders.

**Arresting and Catapult Gear.**

1. Welded structure.
2. Forgings.

**Springs.**

All springs  $\frac{1}{8}$  in. diameter wire and over, as well as functional emergency springs, should be magnetically inspected.

**Miscellaneous.**

1. Welded control assemblies.
2. Ordinance adapter and gear.
3. Primary structure (forgings).
4. Structural welded fittings.

**Magnetization Curves.**—For ease of comparison, magnetization curves are given in Fig. 46. The characteristics of ferromagnetic substances as

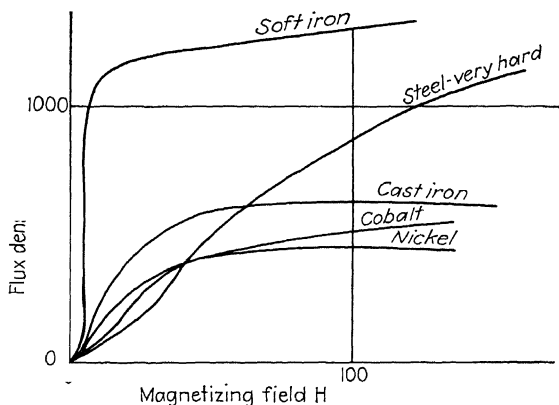


FIG. 46.—Magnetization curves.

shown by this figure are according to Moore. It is easily seen by these curves how evident the different magnetization curves are. It is easily seen that soft iron is quite easily magnetized and becomes saturated at low field strengths and, in turn, develops high flux density. By comparison, the increase in magnetization of hard steel is more gradual but in time approaches the same flux density. Of course, the curves for steel vary with composition.

TABLE 69.—MAGNETIZING CURRENT STRENGTHS FOR AIRCRAFT PARTS

Part	Amperes
Ball ends.....	1,000
Ball, connecting rods.....	2,000
Bolt, crankshaft.....	2,000
Bolt, crankcase.....	500
Bolt, Rocker arm.....	1,000
Bolt, pinion shaft.....	500
Cage, impeller shaft bearing.....	2,500
Cage, pinion.....	2,000
Cam.....	2,500
Crankshaft.....	2,500
Cylinder sleeves.....	1,500
Gears, reduction.....	2,500
Gear, impeller drive.....	1,500
Gear, cam drive.....	2,500
Gear, generator drive.....	2,500
Gear, magneto drive.....	1,000
Gear, oil and fuel pump.....	1,000
Gear, tachometer.....	1,000
Guides, valve tappet.....	2,000
Nut, propeller hub.....	1,500
Nut, thrust.....	1,500
Pin, knuckle.....	1,500
Pin, piston.....	2,000
Pin, tappet roller.....	500
Propeller shafts.....	2,500
Propeller hubs.....	2,500
Push rods.....	1,500
Races, front and rear main bearings.....	2,500
Rocker arm.....	2,000
Rod, master.....	2,500
Rod, articulated.....	2,000
Rollers, tappet and rocker arm.....	1,000
Shaft, impeller...	1,000
Shaft, rocker arm.....	500
Shaft, oil and fuel pump, tachometer S.	1,000
Springs, valve.....	500
Tappet, valve.....	500
Valves.....	1,500
Washer-valve spring.....	2,000
Engine mounts.....	800*
Frames, main stress bearing.....	800*
Fittings, welded.....	1,000
Hooks, arresting gear.....	1,200
Springs, landing gear.....	1,000
Struts, welded ends.....	1,500
Propeller blades.....	1,000
Ribs, control flaps.....	1,000
Tail-wheel fitting and piston.....	1,500
Landing gear, struts and bolts.....	1,500
Wing-hinge fittings.....	1,500
Bomb-rack attachment fittings.....	1,000
Armament installation supports.....	1,000

\* Alternating-current continuous method.



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